
BIOREFINING IN THE WHEATBELT

A scoping study for assessing the feasibility of new biomass projects in Western Australia's Wheatbelt region.

A report submitted to the School of Engineering and Energy, Murdoch University in partial fulfilment of the requirements for the degree of Bachelor of Engineering.

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ABSTRACT

Australia produces biomass through broad acre cropping, as well as by agro-forestry, forestry, and through waste collection. There has been strong interest, particularly over the last decade, in optimizing the value of these biomass resources by looking at new conversion technologies (to create new, high value products), and in utilizing waste streams where they exist. The opportunity may exist to greatly expand biomass industries in Australia, to produce energy and other products, and to address issues like climate change and oil dependency. There may also be the opportunity to improve agricultural sustainability (particularly in the case of salinity and soil degradation in the Wheatbelt) by improving the value of environmentally beneficial crops such as mallee. Most discussion so far on biomass conversion industries has centred on bioenergy (production of heat and power from biomass).

Driven by Australia's relative inaction on bioenergy, all levels of government have made policy statements, and commissioned reports, encouraging biomass energy projects. Despite a strong mandate for industry to pursue bioenergy projects, so far little has changed. It may be possible to combine energy production with other processes to improve value extraction from biomass feedstocks, and so improve the viability of this kind of project. This is an unusual approach to making a business case in that some important desirable outcomes, like addressing climate change and agricultural practices, are external to the business case.

This study looks at biomass resources, local issues, and opportunities in Wheatbelt Western Australia. It seeks to provide a framework for developing projects that deal more broadly with biomass resources, looking for technical and economic synergies, and grouping processes so as to maximize the value extracted from the resource to improve viability of projects.

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TABLE OF CONTENTS

Abstract	2
Acknowledgements	3
Table of Contents	4
Figures	6
Tables	7
Introduction	8
1 Policy Drivers.....	13
1.1 Strategic Documents Referring to Biomass.....	13
1.2 W.A. Policies on Wheatbelt Green Energy, hubs, and Biomass.....	14
1.2.1 Labor.....	15
1.2.2 WA Greens.....	15
1.2.3 WA Liberal-National Coalition	16
1.3 Sustainable Energy and Biomass Funding Opportunities in WA.....	17
1.3.1 SEDO Grants Program	17
1.3.2 Rural Renewable Energy Program.....	17
1.4 Biomass Policy Conclusions	17
2 A Short Primer on Plant Anatomy	19
2.1 Units.....	20
3 Markets.....	21
3.1 Stationary Energy.....	22
3.1.1 Economic Value of Electricity Production	23
3.1.2 Biomass Pellets.....	24
3.2 Biofuels	25
3.2.1 Ethanol (or Bio-ethanol).....	27
3.2.2 Biodiesel	28
3.2.3 Biofuels Overview.....	31
3.2.4 Biofuels Conclusion	32
3.3 Biodegradables	33
3.3.1 Bioplastics.....	33
3.3.2 Examples of Bioplastics	35
3.4 Biomass Unique Products.....	36
3.5 Biolubricants.....	37
3.6 Adhesives	37
3.7 Other Protein Products	38
3.8 Composite materials	38
3.9 Biochar and other soil conditioners	38
3.10 Products and Markets Conclusions	39
4 Technologies	41

4.1	Thermo-chemical Processes.....	42
4.1.1	Combustion	42
4.1.2	Pyrolysis.....	43
4.1.3	Gasification.....	44
4.1.4	Liquefaction.....	45
4.2	Biochemical and Biological Processes.....	45
4.2.1	Fermentation.....	45
4.2.2	Anaerobic Digestion	46
4.3	Mechanical and Non-Biological Chemical Processes	47
4.3.1	Biodiesel	48
4.3.2	Compacted Biofuel	48
4.3.3	Bioethanol Production	49
4.4	Biomass Conversion Technology Conclusions	50
5	Resource assessment.....	53
5.1	Biomass Conversion Product Categories.....	53
5.1.1	Stationary bioenergy	53
5.1.2	Biofuels.....	54
5.1.3	Bioproducts	54
5.1.4	Biotech.....	55
5.2	Biomass Criteria	56
5.3	W.A. Biomass Resources Overview	56
5.3.1	Principle Crops ABARE Crop Report 2009	57
5.3.2	Bioenergy crops.....	58
5.3.3	Residues.....	60
5.3.4	Primary Residues: Crop Residues	60
5.3.5	Primary Residues: Forestry Waste	61
5.3.6	Secondary Residues: Processing Residues	62
5.3.7	Secondary Residues: Tallow and Cooking Oil.....	62
5.3.8	Tertiary Residues: Municipal Green Waste	63
5.3.9	Other Tertiary Residues.....	63
5.4	Overview of Wheatbelt Biomass Resources.....	64
5.4.1	Transport and Handling.....	64
5.4.2	Compensation for Lost Soil Nutrient.....	65
5.4.3	Electricity and Biofuel Conversion Efficiencies.....	65
5.5	Summary of Resource Survey Results.....	66
5.6	Resource Assessment Conclusions	67
6	Industrial Hubs and The Biorefinery Concept.....	69
6.1	Industrial Hubs.....	69
6.2	Biorefinery Concept.....	70
6.2.1	Available Definitions.....	71
6.2.2	For the Purposes of this Study	71
6.3	Biorefineries and Biomass Industry Hubs Conclusions	71
7	Biorefinery Case Study	72

7.1 IWP Overview	72
7.2 Process	73
7.3 IWP Review	74
7.4 IWP Conclusions.....	74
8 Potential Biomass Hub Sites.....	76
8.1 Wagin.....	76
8.1.1 Wagin Site.....	76
8.1.2 Process Overview	76
8.1.3 Groats	77
8.1.4 Hull	77
8.1.5 Quantities.....	77
8.1.6 Proposal.....	77
8.1.7 Wagin Water Woes	78
8.1.8 Notional Design	79
8.1.9 Wagin Conclusions	79
8.2 Williams	81
8.2.1 Proposal.....	81
8.3 Potential Biorefinery Sites Conclusions	89
9 Potential University Involvement.....	90
10 Roadmap for Progressing Biorefinery Projects	93
Conclusions	96
Appendix 1: Resource Details	100
References	103

FIGURES

Figure 1: Wheatbelt Population Trends (ABARE, 2006).....	23
Figure 2: Co2 Emissions by fuel (Beer, Grant, Williams, & Watson, 2002).....	26
Figure 3: Integration of biodegradable plastic into the waste disposal infrastructure (Narayan, 2006)	34
Figure 4: Product pathways for direct biomaterials and/or bioplastics (Narayan, 2006)	34
Figure 5: Biomass Feedstocks and Products that are both directly Extracted and derived (Narayan, 2006)	36
Figure 6: Direct Combustion (CEC, 2008).....	42
Figure 7: Pyrolysis (CEC, 2008).....	43
Figure 8: Gasification and Combined Cycle (CEC, 2008).....	44
Figure 9: Liquefaction Flows (McKendry, 2002)	45
Figure 10: Anaerobic Digestion Process Flows (McKendry, 2002).....	47
Figure 11: Esterification Process flows for Biodiesel (McKendry, 2002)	48

Figure 12: First and Second Generation Biofuel Pathways (O’Connell, 2008).....	52
Figure 13: Overview of W.A. Crops (Wilkins, 2006).....	57
Figure 14: Bioenergy Production Potential (Smeets & Faaij, 2007).....	67
Figure 15: Some Examples of Synergy Flows in the Kwinana Industrial Area (Beers, 2008) .	70
Figure 16: IWP Flow Diagram (OMA, 2008)	73
Figure 17: Schematic Description of a Proposed Integrated Process at Morton Grains in Wagin	79
Figure 18: Esterification Process flows for Biodiesel (McKendry, 2002)	83
Figure 19: Schematic Description For Macco Feeds Proposal at Williams	88

TABLES

Table 1: Electricity Tariff Increases under various Carbon emissions Mitigation Schemes (OOE, 2009)	23
Table 2: Fuel Pathways (ISEE, 2009)	25
Table 3: Ethanol Market (ABARE, 2008; O’Connell, 2008).....	27
Table 4: Biodiesel Market (ABARE, 2008; Mortimer, 2003)	28
Table 5: Comparison of most viable Fuels (ABARE, 2009b; Ramey & Yang, 2004; William J Ryan & Michael L Poole, 2008; USDOE, 2009a)	31
Table 6: Ethanol Greenhouse advantage For Different Time Horizon And Discount Rate Approaches (USEPA, 2009)	32
Table 7: Estimated Market for biolubricants in the USA (Johnson, 2000).....	37
Table 8: W.A. Major Crop data	57
Table 9: Possible Excess Agricultural land by diet and Population scenario (Hoogwijk et al., 2003)	58
Table 10: Fuel Crop Overview	59
Table 11: Primary Residues Overview.....	61
Table 12: Base Case for Economic Analysis	85

INTRODUCTION

There are a number of real and present threats to the Wheatbelt region of WA that are combining to present a real challenge to Australia's largest grain producing region.

- Salinity is endemic and is eating away at arable land in the region (McConnell, 2000)
- Rising water tables have a direct effect on buildings and other infrastructure in the region; energy is being expended over this problem in an ongoing way (WDC, 2009)
- Climate change is affecting rainfall – less in growing season and more out of season, causing further problems (ABARE, 2006)
- Crop markets are unreliable due to globalization of trade (ABARE, 2006)
- Costs are rising with oil price affecting transport and fertilizer costs (William J Ryan & Michael L Poole, 2008)
- Urban drift is depleting town populations (WDC, 2009)

The long-term success, and indeed survival, of the region is at stake. To become a sustainable human settlement there must be some fundamental changes in the way that communities and economic activities are structured in the region. Technical solutions to the immediate environmental problems include groundwater transfer (using pumps) and groundwater redirection (using trenches), and have proved helpful in localized situations. But a broader approach is necessary for long-term regional habitability and development.

One proposal that returns to the table almost every time policy for the Wheatbelt is discussed, is the replanting of the forest cover; re-vegetation. Historically, the Wheatbelt was covered in a particular kind of eucalypt forest, which was first changed by aboriginal use of fire to create a favourable environment for the kangaroos that they were hunting, and was then almost completely cleared by Europeans during the 19th and 20th centuries. (Merrilees, 1968) It is the removal of this forest cover that is widely thought to have caused the water table and salinity issues that now plague the region. Replanting of this forest cover has been well demonstrated to be effective in slowing the spread of dry land salinity. The scale of the problem is too large for a simple intervention by government, meaning that any solution, including re-vegetation, will require financial investment from private as well as public sources, which will in turn require a profit motive.(Abadi, Bartle, & Giles, 2009)

To drive the required investment in re-vegetation an economic driver is required. Carbon sequestration plantings have used the bio-sequestration features of the Kyoto protocol to provide a financial driver for developing plantations in the region. Bioenergy, and other biomass conversion processes, have the potential to provide another financial driver by putting a value on woody crops to the farmer. With correct management, these crops can

provide many of the benefits of forest cover but can also be harvested regularly, and will then re-grow.

Biomass conversion processes also have the potential to address other regional issues. The potential to add value to current agricultural practices by developing new markets for agricultural biomass could be significant. Crop residues, for example, could be converted into energy and other products. Processing wastes could also be utilized. A broader approach to using the resources that are already available in the region could see new industries evolve, along with jobs and regional development. This report will propose the use of crop and processing residues to initiate the development of biorefineries in the region, whilst woody crops are being developed.

There is a strong policy mandate for pursuing new biomass processes, and bioenergy production is seen as particularly urgent. Some key documents point the way as determined by strategists at all levels of government. The **Policy Drivers** section looks at how different elements in government and politics are approaching biomass, and what kind of funding has been made available.

A **Short Primer on Plant Anatomy** is included to give some background on biomass, and introduce key terms.

The methodology for identifying opportunities for biomass conversion projects in the Wheatbelt region is tackled first on a very general level. This involves assessment of resources available in the region, assessment of markets for biomass products and what is driving each market, and a survey of the processes, or technologies, which are available to meet each identified market, based on the feedstocks available. The corresponding sections of this report are **Resource Assessment**, **Market Survey**, and **Technologies**.

A general trend towards clustering of similar industries into hubs is identified, and the implications that this approach has for biomass conversion is examined. The concept of a biorefinery, a facility that embodies biomass conversion processes with multiple streams of inputs and outputs, and that can interact with other collocated industrial facilities, is outlined in the **Industry Hubs and Biorefineries** section.

There are examples of facilities that would be described as biorefineries, according to the concept that is developed in this report. The oil mallee project is a good example of a project that has been developed in this way, and will be discussed in the **Case Study** section.

Some specific possible locations for biomass conversion facilities, and biomass industry hubs, are identified and assessed. There are two Wheatbelt towns, Williams and Wagin, which have processors operating who have already expressed their interest in developing bioenergy facilities, with possible further developments in time. These are examined in the **Potential Biomass Hub Sites** section.

The section on **Potential Murdoch University** involvement examines just that: the research streams being pursued at Murdoch University that could sit into the kind of projects being discussed in this report. Apart from direct consultation on project development, the multi-

process concept of the biorefinery could provide a convenient pathway for commercialization of research streams at Murdoch. Areas that will find a place in the biorefinery concept include:

- Advances on direct combustion for stationary heat and power generation (gasification etc.)
- Desalination (possibly thermal, desalination may provide a kind of energy storage)
- Lignocellulosic hydrolysis processes
- Microbial and algal processes

Finally a **Roadmap** section attempts to outline a way forwards for biomass conversion in the Wheatbelt from low hanging fruit to sustainable long-term thinking. The drivers motivating biomass conversion projects in the Wheatbelt are strong, the technologies, markets, and resources are available and developing quickly, only sustained leadership is required to begin the transformation of the region.

Literature Review

A broad range of publications was reviewed in preparation for this study. The full bibliography is included as an *EndNote* library (with all URL addresses and downloaded PDF files included) on the attached CD.

Documents that were important at all stages of the development of the thesis include:

- Rock Lobster Biofuel Western Australian Study (2008) by William J Ryan and Michael L Poole from the Kondinin Group
 - The Western Rock Lobster Council commissioned this report to assess the feasibility of supplying their fleet with biodiesel. The structure includes an assessment of the drivers (economic and policy), assessment of available resource, and a high level economic assessment of a possible biodiesel plant (William J Ryan & Michael L Poole, 2008)
- Two studies by Deborah O'Connell at CSIRO Sustainable Ecosystems unit were very useful in giving a sense of the state of the industry in terms of technologies and resources
 - Sustainability guide for Bioenergy: A scoping study (2005) with Brian Keating and Mark Glover gives guidelines for developing projects that address broader objectives than just a business case (O'Connell, Keating, & Glover, 2005)
 - Emerging technologies for biofuel production (2008) is a brief update on the state of biofuel technology and the potential of the industry meet transport needs (O'Connell, 2008)

- The Australian Bureau of Agricultural and Resource Economics (ABARE) were useful throughout the report as the authoritative source for statistics and trend analysis. Of particular use were their quarterly Crops Reports (A. B. o. A. a. R. E. ABARE, 2009a), and the energy sections of their commodity reports (ABARE, 2009b)
- The US Department of Energy (USDOE) is has excellent databases of information on biomass technologies and processes, and on resources (although there is a USA focus that limits usefulness)
- Many facts and figures are cited to documents found through the ScienceDirect database, using Murdoch University's license (ScienceDirect, 2009)

Documents that were significant to each chapter of the study are listed:

- Chapter 1 reviews strategic documents at various levels of government. The Clean Energy council produced *Australian Bioenergy Roadmap* (2008) for the Department of the Environment, Water, Heritage and the Arts (DEWHA). Subtitled *Setting the Direction for Biomass in Stationary Energy to 2020 and Beyond*, it is a strategic document, which sets out the argument, and recommends a method, for increasing the amount of biomass derived electricity in Australia from less 1% (currently) to 4% by 2020.
- Chapter 2 gives an introduction to plant anatomy and some terminology. This chapter relies most on *Biology of Plants* (2005) by Peter H. Raven, Ray F. Evert, and Susan E. Eichhorn
- Chapters 3, 4, and 5 cite many sources but some documents were guiding.
 - In Chapter 3 Markets are surveyed, guided by O'Connell (O'Connell, 2008)
 - Chapter 4 surveys biomass conversion technologies, with O'Connell and the CEC Roadmap guiding, and much information from the USDOE (CEC, 2008; O'Connell, 2008; USDOE, 2009a)
 - Chapter 5 Assesses resources in the region and relies heavily on ABARE reports (A. B. o. A. a. R. E. ABARE, 2009b)
- Chapter 6 looks at the biorefinery and biomass industry hub concepts guided by an article on by Wendy Pyper called *Emulating Nature: The rise of industrial ecology* (2006) and on the example of the Kwinana Industrial Zone, as examined by Dick van Beers in *Capturing Regional Synergies in the Kwinana Industrial Area* (Beers, 2008)
- Chapter 7 uses the Integrated Wood Processing plant at Narrogin as an example case study and relies on an in person interview with people from Verve (Conway, 2009), and the Oil Mallee Association website (OMA, 2008)

Other sources are cited throughout this report.

Starting the study at the broadest level, the first chapter looks at Policy drivers, including statements of policy from major political parties, and strategic documents to help define the governmental environment in which biorefinery projects must exist.

1 POLICY DRIVERS

The emergence of new or changing economic opportunity is driven on a number of levels by a number of different kinds of players. Primary producers may be driven to change their practices, or investigate new techniques because they want to improve profit margins, or because they want to label their products as organic, or any number of reasons that they control. These are *personal drivers*. But primary producers can only consider innovative modes of production if the technology is made available by research and development bodies, if regulations allow the use of those innovations, and if businesses make the technology available. These are known as *mega-drivers*. (Farmer-Bowers et al., 2006) These are decisions about the infrastructure that is available, the governmental regulations that hold, taxation etc. that are decided by others, and that the primary producer may have little influence over. These mega-drivers determine the range of opportunities that will present to the primary producer, and how appealing the opportunities will be perceived as being.

To make an assessment of mega-drivers at play in the Wheatbelt, this section will look at policy statements from administrative bodies and major political parties, and at funding opportunities that are offered through various government offices.

1.1 STRATEGIC DOCUMENTS REFERRING TO BIOMASS

All three levels of government that operate in the Wheatbelt have guiding documents that emphasize the need for improved development of renewable and regional energy resources. Energy from biomass will play a key role in improving energy security and greenhouse footprints in regional areas, and the combination of bioenergy with biorefineries connects into the wider need for jobs and

- Federal
 - Australian Bioenergy Roadmap (DEWHA) (CEC, 2008)

The Clean Energy Council (CEC) produced a strategic paper titled *Australian Bioenergy Roadmap* for the Federal Department of Environment, Water, Heritage, and the Arts (DEWHA) in September 2008. The Roadmap document is subtitled *Setting the Direction for Biomass in Stationary Energy to 2020 and Beyond*. The roadmap uses climate change as the primary driver for investing in stationary bioenergy, but makes the argument that other countries have matured the technologies involved, and have achieved much higher fractions of bioenergy in their domestic energy mixes, paving the way for Australia to take advantage of ample biomass resources such as agricultural residues. The overall recommendation is that Australia aim for sourcing 4% of electricity from biomass feedstocks by 2020.

- State

- W.A. Office of Energy Strategic plan 2007-2030 (O. o. E. OOE, 2007)

The WA Office of Energy Strategic plan does not refer to particular technologies, but does make a specific objective of increasing regional energy production from renewable sources. It makes a succinct introduction to modern energy policy: *Two key strategic issues face energy policy makers internationally, nationally and locally - climate change and energy security.* While this document does not point specifically to bioenergy, and biorefineries, the state government has been subsidizing tangible moves in that direction. Funding was provided to the oil mallee project, discussed in Chapter 7, and studies of potential fuel crops have been carried out through the Department of Agriculture and Food.

- Regional

- Wheatbelt Development Commission submission to State Infrastructure Strategy (WDC, 2006)

This submission to the State Infrastructure Strategy is explicit about the need to look at biomass as a source of energy and economic development in the Wheatbelt. It suggests that energy infrastructure for the region should *encourage the establishment of embedded renewable generation capacity within the region i.e.: wind generation and bio-mass generation.* It also refers to the need to look at embedded desalination plants in the same way, which paves the way for interesting synergies between water and power in regional areas.

- The Wheatbelt Development Commission Strategic Plan (2009-2012) (WDC, 2009)

Makes no mention of bioenergy potentials but does refer to an active need to pursue distributed generation. Bioenergy plants make excellent distributed generation and fringe of grid support tools because the electricity produced is highly predictable, and because the power (and heat) will often be produced at an industrial site that is also a heavy energy consumer. The strategic plan also talks about desalination and water treatment as important themes.

1.2 W.A. POLICIES ON WHEATBELT GREEN ENERGY, HUBS, AND BIOMASS

The three major political parties that operate in the Wheatbelt have made policy statement regarding biomass resource development.

1.2.1 LABOR

The WA Labor Party policy statements tend to be focused on renewable energy in general, and particularly on *green jobs*.

WA Needs More Green Jobs Not More Carbon Concessions

(Press Release: Alannah MacTiernan MLA, Shadow Minister for Climate Change, 20 February 2009)

(MacTiernan, 2009)

Western Australia should be focused on securing national funding to develop new green energy technologies, rather than watering down the Emissions Trading Scheme, Shadow Minister for Climate Change Alannah MacTiernan said today.

"We need to fight harder to access the \$5 billion Clean Coal fund, the \$500 million Renewable Energy fund and the \$12 billion Building Australia fund," Ms MacTiernan said.

"If the State Government only focuses on the Emissions Trading Scheme concessions we will fail to generate green jobs for the future."

Ms MacTiernan said there were exciting new technology projects that Western Australia could develop including:

- A bio-sequestration process for Collie coal;
- A geo-sequesterian process for gas on Barrow Island;
- Wave power projects on the southern and south-west coast;
- Solar thermal and geo-thermal projects on a Pilbara interconnected grid; and
- Biomass plants in the Wheatbelt and southern coastal areas.

W.A. Labor Platform as amended June 2008 p75

15. Labor believes that prudent planning and international responsibilities require a shift to the

renewable energy resources: solar, wind, biomass and rural and urban waste and

maximisation of opportunities for cogeneration.

(ALP, 2008)

1.2.2 WA GREENS

The WA Greens have a very specific platform of regional policies, including the Wheatbelt. Bioenergy features strongly and is referred to specifically (as distinct from general statements about renewables).

From the WA Greens' Wheatbelt Rejuvenation statement:

Biorefining in the Wheatbelt

- establish the region as the renewable energy hub through a network of solar, wind, geothermal and bio-energy production facilities
- utilise Carbon Trading and Mandated Renewable Energy Targets in a development plan to drive investment in renewable energy and tree farming in rural regions
- expand oil mallee and other native vegetation planting across 20% of the Wheatbelt to reverse salinity, restore degraded land and provide feedstock for bio-energy
- restore and upgrade regional rail, road and power distribution networks
- promote climate and energy economic initiatives to revitalise and repopulate regional towns and communities
- develop the potential of soil carbon to enhance viability of Wheatbelt agriculture
- invest in research and the development of other sustainable future farm industries

Re-powering the South West

- make our regional towns, farms and communities renewable energy producers for the State
- guarantee profitable feed in tariffs for all renewable power sources
- facilitate rapid connection of renewable energy technologies to the grid
- rebuild and strengthen the electricity grid to pump energy from the regions to the cities
- establish an agency to coordinate and facilitate the rapid uptake of energy efficiency and renewable energy technologies
- immediately halt the construction of new coal fired power stations
- use Carbon Trading and Mandated Renewable Energy Targets to drive investment in renewable energy and energy efficiencies

(AGP, 2008)

1.2.3 WA LIBERAL-NATIONAL COALITION

The Liberal-National policy statements, and 2009 budget allocations, have been generally focused on agricultural research and development, with little specific mention of biomass industries, bioenergy, or even of renewable energy.

A Liberal government will allocate up to \$250,000 to commission an independent engineering assessment of the feasibility of treating large saline reserves east of the Darling Escarpment to reduce saline discharge into our waterways and enhance water resources for the coastal plain. (WALP, 2009)

\$6.9million for many projects to facilitate the sustainable ongoing development of the cropping and livestock industries based in the Wheatbelt.

\$1.4million for farming systems projects and the provision of information and analytical tools to assist farmers evaluate sustainable farming systems in response to issues, such as climate change, herbicide resistance and the introduction of genetically modified crop varieties. (Buswell, 2009)

1.3 SUSTAINABLE ENERGY AND BIOMASS FUNDING OPPORTUNITIES IN WA

The WA Sustainable Energy Development Office (SEDO) administers funding for renewable energy projects on behalf of state and federal governments. There are funding opportunities for off grid projects but these will not apply to most likely locations for biomass hubs.

1.3.1 SEDO GRANTS PROGRAM

The SEDO Grants Program provides grants ranging from \$5,000 to \$50,000 for:

- Community-based sustainable energy projects; and
- Sustainable energy research and development projects.

Grant applications are invited through competitive funding rounds. Applications must meet all the requirements set out in the relevant *Program Guidelines* to be eligible for funding.

1.3.2 RURAL RENEWABLE ENERGY PROGRAM

Funding has now been fully allocated for the Rural Renewable Energy Program and this program has now closed.

The Rural Renewable Energy Program provided rebates for grid-connect renewable energy power systems in specific 'fringe of grid' areas of the South West electricity grid. The program was supported by the Australian Government through the Renewable Remote Power Generation Program, which is administered in Western Australia by the State Government's Sustainable Energy Development Office. The program provided rebates (typically up to 50%) for renewable energy power systems with a rated capacity of 500W to 2MW connected to 'fringe of grid' areas of the South West electricity grid.

(SEDO, 2009)

1.4 BIOMASS POLICY CONCLUSIONS

There is a general feeling that bioenergy is seen as having a place in the Australian energy sector, but remains far from the mainstream. The recently expanded mandatory renewable energy target (MRET) requires that 20% of Australian electricity comes from renewable sources, including bioenergy. Recent modelling by McLennan Magasanik Associates, for the

Department of Climate Change (Gerardi, 2009), predicted that the 20 per cent renewable target will deliver a mix of plant types:

Biomass	17%
Geothermal	23%
Wind	56%
Hydro	4 %

Given that mega-drivers are mandated by policy (to at least some extent), a survey of what markets exist may add to the impetus for players in the Wheatbelt to look more closely at the opportunities that a biorefinery may provide? Firstly, to aid further analysis, a brief review of plant anatomy is provided to help with concepts and terminology.

2 A SHORT PRIMER ON PLANT ANATOMY

Before entering into the more technical aspects of biomass conversion processes and biorefineries, it may be useful to review some basic plant biology for some grounding in the basic components of plants, and the terminology.

Although there are many thousands of different organic molecules, most of the dry weight of plants (and all living things) is made up of four basic types. These are carbohydrates (sugars and chains of sugars), lipids (fatty acids), proteins (amino acids), and nucleic acids (DNA and RNA, made up of nucleotides). Lignin is the woody form of cellulose, a carbohydrate.

The parts of plant architecture that will be referred to most often in this report include lignocellulosics (woody cellulose), sugar/starch (polysaccharides), oil content (lipids), proteins, energy content (usually meaning the calorific value from burning by dry weight), and the ash content (the silicon dioxide and trace minerals that remain after burning).

Lignocellulosic material

The lignocellulosic materials form the woody part of a plant. Lignin forms part of some plant cell walls by weaving itself amongst the cellulose and hemicellulose of the cell wall. These cellulosic materials are not usually available as food (except to animals like termites and cockroaches that have enzymes in their digestive tracts to break the cellulose down into sugars) but contain energy which may be released by processes such as combustion. Cellulose is a natural polymer, formed by the combination of many sugar, or *saccharide* molecules. As such, there is potential for use in bioplastics production, with *Rayon* being an example of a well established, commercial cellulosic polymer. (Raven, Evert, & Eichhorn, 2005; Sun & Wool, 2005)

Sugar/Starch

Like cellulose, sugars and starches are carbohydrates (polymers formed by the combination of saccharides). This form of water soluble carbohydrate is used by plants to store energy, and is fermented to produce ethanol.

Sugars occur in plants in raw forms (such as in sugar cane) but these crops are not common in the Wheatbelt. Hemi-cellulose (closely related to starch, and used increasingly in fermentation processes) is much more common, but requires extraction by hydrolysis (steeping in weak acid or weak base). (O'Connell, 2008; Raven et al., 2005)

Lipids

Lipids are also molecules used by plants for energy storage, usually in the form of fats or oils. These materials are non soluble in water, and are more energy dense (approx. 3 times) than carbohydrates. Lipids can be combusted to access the contained energy, but may also

be transformed into other materials or fuels. A common fuel producing process using lipids is the transesterification of plant oils into biodiesel. (O'Connell, 2008; Raven et al., 2005)

Proteins

Proteins are very large, very complex molecules, with a large variety of functions in living things. Most organisms have proteins as 50% or more of their dry weight. Plants are different because they instead have a high proportion of cellulose. The highest protein occurrences in plants occur in certain seeds, with up 40% of dry weight. (Raven et al., 2005) The main use of proteins in the context of a biorefinery is to produce adhesives.

Energy Content

The energy content is the energy density of the material measured in energy per unit weight (e.g. gigajoules per tonne, GJ/t). Energy content was known as calorific value, because the calorie was a common energy unit before the SI system was standardised. Energy content will be generally quoted in terms of the dry weight of material, unless this is not appropriate (e.g. pyrolysis oil). Energy content is measured using a bomb calorimeter, or similar.

Ash Content

Ash is the inorganic part of biomass that remains after high temperature combustion. It is a mixture of oxide compounds. The proportions of ash components can be tuned to some degree by combustion conditions, as seen in a new process being developed to produce high grade silicon oxide (SiO₂) for thin film photovoltaic cell production. Combustion burners must be tuned to the ash content of the feedstock, as well as the behaviour of that ash at the temperatures involved.

2.1 UNITS

Units used include:

Quantity	Unit	Symbol	10 ³	10 ⁶	10 ⁹
Mass	kilogram	kg	Tonne (t)	kt	Mt
Heat energy	joule	J	kJ	MJ	GJ
Electric energy	Watt-hour	Wh	kWh	MWh	GWh
Electric power	watt	W	kW	MW	GW
Volume	litre	L	kL	ML	GL
Area	Hectare	ha (10000m ²)	kha	Mha	
Energy density	Joule per litre	J/L	KJ/L	MJ/L	GJ/L
Specific energy	Joule per kg	J/kg	KJ/kg	MJ/kg	GJ/kg

Conversions: 1 MWh = 3.6 GJ

3 MARKETS

This chapter presents a survey of biomass-derived products and their possible markets. The focus is on products that could potentially be produced from Wheatbelt WA crops. The products are considered in the context of uses, production processes (general and commercialised examples), economic value, and government regulation.

There are number of drivers behind the markets for biomass derived products including concerns over oil reserves, the need to reduce carbon emissions, the ongoing search for new products, and the opportunity presented by some biomass resources where they have little or no value to producers (e.g. agricultural waste streams).

The ever shrinking reserves of crude oil, and the growing consensus that *peak oil* (the horizon when world oil production rate begins terminal decline) has already occurred (Schroeder, 2004), drives the desire to begin systematically replacing important petrochemical products with renewable, plant based versions. Many products that are now dependent on the petrochemical industry for large scale production were once based on plant material. Early fibres, plastics, medicines, solvents, and dyes all had plant based biomass origins. (O'Connell, 2008)

Carbon emissions are coming under more and more scrutiny, and there is increasing pressure to mitigate emissions. The carbon cycle of biomass (the fact that the plants fix carbon from the atmosphere as they grow) means that biomass-derived products will be less exposed to coming financial penalties for emissions in production. There is also the opportunity to add value to biomass processes by providing a sink for carbon. For example, oil mallee trees that are being grown to provide a resource for biorefineries in the Wheatbelt W.A., also fix CO₂ in root mass. The above ground part of the plant is harvested, but large amounts of carbon remain fixed in the rootstock, from which the plant re-grows. (Wu, Fu, Giles, & Bartle, 2005)

Related to carbon emission issues, but separated in policy and regulation in the current Australian context, is the requirement for large energy consumers to supply some of their load from renewable sources. The newly passed Mandatory Renewable Energy Target (MRET) requires that large Australian energy consumers are sourcing 20% of their electricity from renewable sources by 2020. Bioenergy is a renewable energy listed in the Renewable Energy (Electricity) Act (2000), entitling bioenergy electricity generators to claim renewable energy certificates (RECs) for sale into the MRET system. (DCC, 2009)

The search for new products, or variations on existing products, is constant and ongoing in the modern industrial world. Biomass conversion processes have the potential to offer products that are new, or are new versions of existing products, and that are produced in a renewable cycle. Biodegradable versions of problem products, such as plastic shopping bags, are of great interest. Whilst there are many examples of enthusiasm for new processes and products creating environmental disasters, it should be possible to manage

this aspect of industry, particularly in the context of a biorefinery with a *zero emissions* (closed loop) approach. (Das, 2005; O’Connell, 2008)

The biomass resources available in the Wheatbelt are examined in the *Resources* chapter, but it can be observed that there are significant agricultural and processor biomass ‘waste’ streams present. If these resources can be utilized to meet the needs of one, or more, of the above drivers, there is the potential to add diversity to the income streams of farmers and processors in the region.

The broad market sectors to be examined are:

- Stationary energy (production of electricity and/or heat at a site)
- Biofuels (transport fuels from biomass)
- Petro-chemical replacement products (solvents, lubricants, plastics etc.)
- New products with valuable properties (cosmetics, medicines etc.)
- Biomass conversion co-product opportunities (such as the large volumes of glycerol coming from biodiesel production by transesterification)

3.1 STATIONARY ENERGY

Demand for stationary bioenergy generation is driven by:

- The need to diversify primary energy sources because of scarce oil supplies and for energy security
- The increasing pressure (and coming regulatory necessity) to reduce greenhouse gas emissions
- The existence of biomass waste streams that have high energy content, and so make for low cost feedstocks

The Clean Energy Council (CEC), on behalf of the Department of Environment, Water, Heritage, and the Arts, designed a bioenergy roadmap for Australia in 2008. A key recommendation of the roadmap report was to increase the supply of electricity by biomass from the current 0.9% Australia wide to around 4%. This figure is achievable based on the resource assessment that was carried out and is in line with European electricity profiles that contain 4-14% bioenergy components. (CEC, 2008)

In W.A.’s Wheatbelt, the agricultural nature of most economic activity means that the main energy requirement in the region is transport fuel. Stationary energy requirements are for electricity and heat. Heat is required by industry, including agricultural processors.

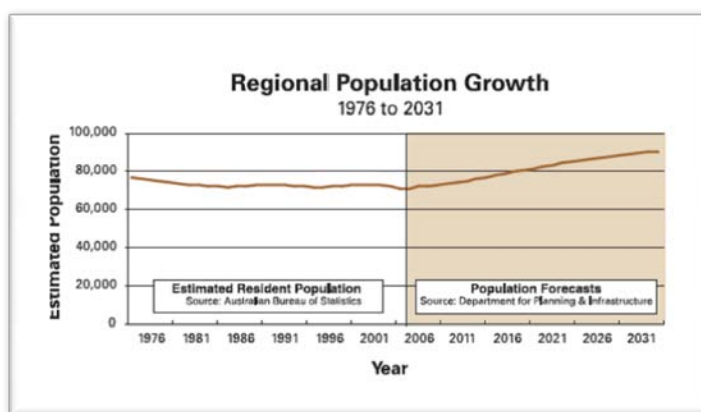


FIGURE 1: WHEATBELT POPULATION TRENDS (ABARE, 2006)

The population of the Wheatbelt is currently approximately 72,000 people, and is expected to grow to around 90,000 people by 2030 (see Figure 1). The energy consumption of the current population is, on average, 20kWh per day per household. (DPC, 2007) By national averages, 2.5 people live in each household, meaning that there are approximately 28,800 households in the Wheatbelt.

Total electricity use in Australia was 242,500GWh and in WA was 14,500GWh (6% of national consumption) in 2008. (ABARE, 2009b) The total residential electricity consumption in the Wheatbelt is 576 MWh/day, or 210 GWh annually.

3.1.1 ECONOMIC VALUE OF ELECTRICITY PRODUCTION

3.1.1.1 TARIFF TRENDS

The cost of electricity in Australia is increasing as a State Government subsidy, which has been in place for many years, is being removed. (O. o. E. OOE, 2009) There will very likely be cost increases with the implementation of economic strategies for greenhouse gas mitigation come into effect. Predicted price rises are shown in Table 1.

TABLE 1: ELECTRICITY TARIFF INCREASES UNDER VARIOUS CARBON EMISSIONS MITIGATION SCHEMES (OOE, 2009)

	CPRS -5			CPRS-15			Garnaut -10			Garnaut -25		
	2010-15	2015-20	2045-50	2010-15	2015-20	2045-50	2013-15	2015-20	2045-50	2013-15	2015-20	2045-50
	Per cent			Per cent			Per cent			Per cent		
NSW	23	27	33	25	29	48	25	24	41	38	39	52
VIC	23	30	37	23	31	52	25	26	35	44	46	59
QLD	21	25	37	24	26	45	26	24	44	44	41	51
SA	21	22	20	21	22	38	26	23	27	39	35	34
TAS	16	25	22	18	27	33	21	21	21	40	39	38
SWIS	11	14	34	12	13	39	10	13	33	20	23	47
NT	5	5	12	7	7	17	3	5	16	9	11	37
Avg	20	25	34	22	26	46	23	23	38	38	38	51

Based on these figures, the current wholesale price of approximately \$35/MWh is expected to increase by 60% over the next few years due to a combination of carbon pricing and tariff reform in WA.

3.1.1.2 RECs

A Renewable Energy Certificate (REC) is created by the Office of the Renewable Energy Regulator (ORER) for every MWh of electricity generated by a registered renewable energy generator. Companies that have obligations under the Mandatory Renewable Energy Target (MRET, soon to be replaced by the RET) purchase RECs through a market to satisfy their obligation. Technologies that qualify as 'renewable' for this scheme are those listed the Federal Government's Renewable Energy Act (2000), including bioenergy. A bioenergy generator should not be considered a 'liable party', required to retire RECs under the scheme, unless they become purchasers of wholesale electricity, as well as generators.

RECs are bought and sold through a market, but the maximum value of a REC is essentially fixed by the shortfall penalty plus some tax advantage to buying RECs. This shortfall penalty is about to increase from \$40/MWh to \$65/MWh not accounted for by retired RECs. Currently (November 2009) the REC price has dropped to \$23/MWh because of oversupply on the market. This oversupply is due mainly to solar hot water systems being made eligible REC producers, and also the increased uptake of solar PV during the first half of 2009. This low price is not expected to recover for two years, unless there are further adjustments to the scheme. (CEC, 2009; ORER, 2009)

3.1.1.3 STATIONARY ENERGY VALUE OF BIOENERGY

FEEDSTOCK

Based on price trends and REC values, the wholesale value of a megawatt-hour of electricity can be estimated. The wholesale price of electricity is around \$35/MWh on average, but deviation is large even over the course of a day. REC values are expected to remain below \$30/MWh for the next two years, so the aggregate value of renewable electricity is \$65/MWh, expected to reach \$85/MWh over the next few years with carbon prices and tariff reform.

From this value, based on 20% efficiency for conversion of biomass to electricity, a value can be put on the energy content of biomass feedstock for stationary energy of \$13/MWh of energy content. This is equivalent to \$3.60/GJ of energy contained in the feedstock. For wheat chaff, for example, the energy content is approximately 12.8GJ/t, meaning that the electricity value of that chaff in a thermal generation process is around \$46/t at current prices.

3.1.2 BIOMASS PELLETS

Biomass pellets are becoming widely used in stationary energy applications in Europe. Pellets are by milling and compression, in a similar way to animal feed pellets. They are also heated to achieve low moisture content and better energy density. The final product has a dark look, not unlike coal, with a similar energy density.

The market for fuel pellets is currently limited to the export market. Prices in Europe are linked to the price of coal because so much of the fuel pellet market goes to co-firing. Price

for export pellets might be around \$60/t based on current coal prices and the energy content of biomass pellets relative to coal.

Assuming that co-firing of biomass pellets could achieve the same levels as are seen in Europe, a local market can be estimated. Studies suggest that co-firing up to 20% pellets should not be problematic for a coal fired thermal power station. (Grassi & Senechal, 2008) The Amager Power Station in Copenhagen, Denmark, is reportedly co-firing at this level. (Christiansen, 2009)

Of approximately 5.2GW generation capacity in WA, approximately 2.2GW are coal fired, or 42.3%. The average load is actually around 1.64GW over the year, so coal fired output is, conservatively, around 0.7GW continuously over the year (OOE, 2008). WA black coal has an energy content of 19.7GJ/t (ABARE, 2009b) and produces electricity with a thermal efficiency of 35-36% (Diesendorf, 2005). This equates to approximately 3.22Mt/yr WA black coal consumed for electricity generation. If 20% of this energy were to be met by biomass pellets, 0.64Mt/y would be required, assuming a similar energy content to coal. The Plantation Energy facility at Albany is producing 0.25Mt for export under a three year contract. It is likely that any local biomass demand will be met from new facilities.

3.2 BIOFUELS

Although any material used for its energy storage properties could be considered a fuel, the term is used here to refer to liquid transport fuels (and some gases). Those derived from fossil sources include petrol (gasoline), diesel, and liquid petroleum gas. Table 2 shows a range of raw materials and the fuels that can potentially be produced from them. Biofuels are liquid transport fuels produced by the conversion of biomass. Biofuels are being actively developed as alternatives to crude oil based fuels.

TABLE 2: FUEL PATHWAYS (ISEE, 2009)

Feedstock	Transport Fuel	Feedstock	Transport Fuel
Crude oil	Gasoline (Petrol)	Electricity (fossil, nuclear)	Hydrogen
	Diesel	Biomass (Ligno-cellulosics)	Ethanol
Coal	Gasoline		Methanol
	Methanol		FT-diesel, FY-naptha
	Hydrogen		Hydrogen
Natural Gas	CNG	Biomass (sugars)	Ethanol
	Methanol	Biomass (oils)	Plant oil
	FT-diesel, FY-naptha		Biodiesel
	Hydrogen	Biogas	CMG (Methane)
Electricity (Renewable)	Hydrogen		Hydrogen

Drivers for the development of alternatives to crude oil based fuels include:

- Reduction of dependence on imported crude oil

- Reduction of green house gas emissions from transport fuels
- Increased competition in the fuel market to regulate prices
- Anticipation of future scarcity of oil supplies

Australia imports approximately 30% of the oil it consumes. (ABARE, 2008) This represents major energy dependence, which would be of concern to any modern economy. Improved energy security depends on national (and even local) fuel production.

Greenhouse gas emissions from the transport sector represented 13.2% of Australia's total reportable emissions in 2007, and will have grown by 26.5% since 1990. Road transport accounts for almost 90% of transport emissions in Australia. (APH, 2009) The life cycle of a biofuel is generally accepted to be carbon neutral excepting any fossil fuel inputs during cultivation, harvesting and transport (which can be significant), whereas crude oil derived fuels release CO₂ that has not been present in the atmosphere for millennia. The emissions from biofuels are counted as the CO₂ equivalent emissions during production (including farming, transport, and processing). Figure 2 shows a comparison of emissions for different fuels, and demonstrates that, while emissions are far lower for biofuels, they are by no means carbon neutral under current production regimes. Production emissions could be mitigated once more biofuels, and renewable heat and power are available.

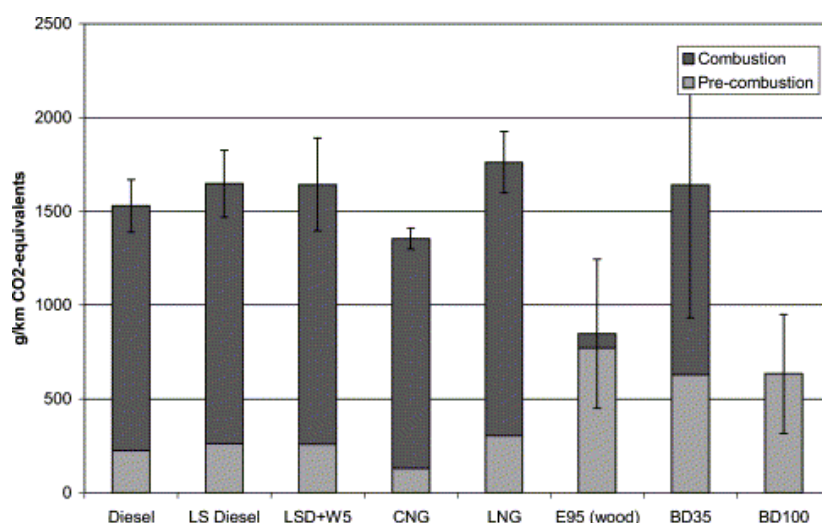


FIGURE 2: CO₂ EMISSIONS BY FUEL (BEER, GRANT, WILLIAMS, & WATSON, 2002)

Increasing the number of fuels that have market acceptance will increase price competition, assuming that the number of suppliers also increases. (Barta, 2008) The arrival in Australia of *flex-fuel* cars, which can run on a range of fuels (usually ULP and ethanol, but other alcohol fuels may be adaptable), has been slow but the technology is well developed elsewhere.

There is general consensus that peak oil is occurring now (in a range of *a few years ago* to *within a few years*). (Schroeder, 2004) Crude oil will become more expensive as supply tightens. The supply may extend as higher prices make marginal sources (such as tar sands)

more profitable, but the future decline in supply and increase in price is certain because the resource is finite.

Established biofuels are ethanol and biodiesel. Total production of these fuels in 2006-07 is estimated at 160 ML (ABARE, 2008)

3.2.1 ETHANOL (OR BIO-ETHANOL)

Ethanol (or ethyl alcohol, C_2H_5OH) is a clear colorless liquid, it is biodegradable, low in toxicity and causes little environmental pollution if spilt. Ethanol burns to produce carbon dioxide and water.

Ethanol is a high octane fuel and has replaced lead as an octane enhancer in petrol. Blending ethanol with petrol oxygenates the fuel mixture so it burns more completely and reduces polluting emissions. Ethanol fuel blends are widely sold in the United States. The most common blend is 10% ethanol and 90% petrol (E10). This blend is now widely available in Australia. Vehicle engines require no modifications to run on E10 and vehicle warranties are unaffected also. Only flexible fuel vehicles can run on up to 85% ethanol and 15% petrol blends (E85), but this blend is becoming more common overseas. (CSR, 2001)

First generation technologies for ethanol production are those that are based on fermentation of sugar and starch crops (sugar cane and corn are common feed stocks). 2nd generation ethanol production will involve more advanced hydrolysis of lignin (woody) biomass feed stocks (increasing the potential resource enormously). 2nd generation processes are not fully commercialised. (O'Connell, 2008)

Potential Market

The market for ethanol as a fuel is based on the petrol market. Ethanol has a lower energy content, so the number of litres of ethanol required to do the same work as a given number of litres of petrol is higher by 46%. (ABARE, 2008) See Table 3.

Total automotive gasoline (petrol) consumed in 2006-07 was 19251 ML. (ABARE, 2008)

TABLE 3: ETHANOL MARKET (ABARE, 2008; O'CONNELL, 2008)

Common Fuel Mixes	Energy Content MJ/L	Consumed 2006-07 (ML)	Potential Ethanol Market (ML)
Gasoline (petrol, E0)	34.2	19251	
E10	33.1		2814
E85	25.0		23916
E100	23.4		28136

CSIRO studies have estimated the possible contribution to Australia's transport fuel mix by ethanol produced in Australia with first generation technologies. Based on 10 years of commodity statistics (to 2007), and assuming just the export fractions of wheat and other hard grains would be available, upper limits of 11-22% of the market could be supplied. (O'Connell, 2008)

3.2.2 BIODIESEL

Diesel engines are capable of burning unprocessed vegetable oil, if the viscosity is sufficient. This can be achieved by heating the oil on its way to the diesel injector pump, but more often the oil is modified to produce *biodiesel*.

1st generation technology for biodiesel production relies on lipids (vegetable oils or animal fats). The extracted oil is then treated by a process known as transesterification to improve viscosity. The oil is mixed with an alcohol (often methanol) and a catalyst (often sodium hydroxide), and reacts to form methyl esters (biodiesel) and glycerol. (NBB, 2009)

2nd generation approaches may include thermochemical conversion techniques that can operate on anything with oil content. New feedstocks may include algae. BTL (or Biomass-to-Liquid fuel) is produced in a multistep process that uses gasification followed by Fischer-Tropsch processing (a method for catalytic reacting of the CO and H₂ in syngas to form hydrocarbon products) to produce liquid fuel from biomass. Unlike other processes, this uses the whole plant to increase the yield of the final product. *Renewable Diesel* employs catalytic hydro conversion of the mixture of diesel fractions and vegetable oil in a hydrotreatment reactor in a controlled environment of high temperatures and hydrogen pressure.

Potential Market

Total automotive gasoline (petrol) consumed in 2006-07 was 17028 ML. (ABARE, 2008) See Table 4.

Energy density of biodiesel depends to some extent on the feed stock. An accepted figure is 37.3 MJ/L. (Mortimer, 2003)

TABLE 4: BIODIESEL MARKET (ABARE, 2008; MORTIMER, 2003)

Common Fuel Mixes	Energy Content MJ/L	Consumed 2006-07 (ML)	Potential Ethanol Market (ML)
Mineral Diesel (BD0)	38.6	17028	
BD5	38.6		881
BD20	38.3		3524
BD100	37.3		17621

Again, CSIRO studies have estimated the possible contribution to Australia's transport fuel mix by biodiesel produced in Australia with 1st generation technologies. Upper limits of 4-8% of the market could be supplied from conversion of domestic waste oil, tallow exports and oilseed exports. (O'Connell, 2008)

3.2.2.1 EMERGING BIOFUELS

This section is based on information from O'Connell and from the US Department of Energy (O'Connell, 2008; USDOE, 2009a), with other sources cited in line.

3.2.2.2 BIOBUTANOL

Butanol, or butyl alcohol (C_4H_9OH) is longer chain molecule than ethanol, more closely related to gasoline. It has an energy density of 29.2 MJ/L, approximately 10-15% less than gasoline. There is anecdotal evidence that it can be used unmixed (100% butanol) in unmodified car engines designed to burn gasoline, partly because butanol is less corrosive than ethanol. The major current use for butanol is as an industrial solvent. (USDOE, 2009a)

Butanol can be produced from biomass (biobutanol), but is currently produced mainly by a petro-chemical process. The traditional method for producing biobutanol is by fermentation, similar to the first generation ethanol process. New methods have been developed and are emerging commercially.

Improved enzymatic processes promise better hydrolysis and better yields from the traditional fermentation approach. (Suszkiw, 2008) Gasification of biomass can produce gases that can then be reformed to produce biobutanol. (Austin, 2009) Important in the forming of fuels from gasification is the *Fischer-Tropsch Process*, a method for catalytic reacting of CO and H_2 (the main constituents of synthesis gas, or *syngas*) to form hydrocarbon products like butanol.

3.2.2.3 BIO-ETBE

Bio-ETBE ($C_6H_{14}O$) is an oxygenate (ether) that, similar to bio-ethanol, can be used as substitute for gasoline in a blend with conventional (fossil) gasoline. ETBE also acts as an octane booster. Bio-ETBE has an energy density of 27 MJ/L.

Bio-ETBE is produced by mixing bio-ethanol (47%v) and isobutylene (53%v) in the presence of a catalyst. Isobutylene can be isolated from refinery streams by reaction with sulfuric acid or by catalytic dehydration of isobutene.

The GHG advantage of Bio-ETBE depends on the ethanol from which it is made.

3.2.2.4 BIOMETHANOL

Bio-methanol (CH_3OH) is an alcohol that can be used in a blend with gasoline, or as a substitute for gasoline. It has a much lower energy density than gasoline of 16 MJ/L. Methanol was used for a long time in the production of the octane boosting gasoline additive MTBE, until this was discovered to be carcinogenic and banned in most countries. Biomethanol is toxic to humans and corrosive. Methanol has been considered for fuel cells, because a liquid fuel would be more convenient than hydrogen gas. Methanol is also an important reactant in the trans-esterification process for biodiesel production.

Bio-methanol can be produced naturally by the anaerobic metabolism of numerous types of bacteria. Methanol can also be produced synthetically by using natural gas. Natural gas and steam are reformed to produce syngas in a furnace, which are then catalytically reacted to form methanol in a version of the Fischer-Tropsch Process.

Advanced methods of methanol production from biomass are not common in the literature; the gasification approach used with natural gas may be adaptable to biomass gasification.

The EGE footprint of methanol is dependent on the feedstock and process energy consumption.

3.2.2.5 Bio-DME

Bio-DME (C_2H_6O) is a colourless, gaseous ether that can be used in diesel and gasoline engines and in gas turbines. It works particularly well in diesel engines because of its high cetane number. Cetane Number (CN) is a measure of combustion effectiveness of a diesel fuel. Diesel engines run well with fuels with CN 40-55. Bio-DME is CN 55. Bio-DME contains 19 MJ/L.

Bio-DME can be produced from methanol. In second-generation production, lignocellulosic biomass is gasified to produce syngas, which is in turn transformed into DME.

The EGE and sustainability footprint of DME depend on feedstocks and production process.

3.2.2.6 BIOGAS

Biogas is a gaseous fuel consisting mainly of the hydrocarbon methane. Biogas can be used in compressed (usually around 200 bar) form to fuel spark ignition engines. It can also be used in diesel engines when supplied in combination with diesel via separate tanks and injection systems. A small percentage (ca. 10%) of bio diesel or synthetic diesel is used to achieve compression ignition. In this option, biogas is used in cooled, liquid form. Energy density is around 32 MJ/m³.

Biogas can be extracted from sewage treatment plants, refuse dumps and other sources of biologically degradable material. The fuel can also be produced by biomass gasification.

Biogas is a gas mixture, consisting of approximately 40 to 75% methane (CH_4), 25 to 60% carbon dioxide (CO_2), and approximately 2% of other gases (hydrogen, hydrogen sulphide and carbon monoxide). Biogas develops through anaerobic fermentation. During this process, organic substances are decomposed by micro-organisms. The substances added to the system produce the biogas in an oxygen-free environment. In the first step, the organic substances are divided into molecular components (sugar, amino acids, glycerine and fatty acids). Microorganisms convert these intermediate products into hydrogen and carbon dioxide, which are then transformed into methane and water according to the equation: $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$.

GHG reduction potential is high in situations like landfill or sewage plants, where methane may be released anyway. In situations where this methane would otherwise be flared, the GHG reduction depends on the efficiency of the energy conversion at the particular facility.

3.2.2.7 HYDROGEN

Hydrogen is an energy carrier not an energy source. It can be used as a fuel for a hydrogen internal combustion engine or for use in fuel cells. Hydrogen has a very high energy content by weight but, in the highly compressed liquid form in which it is generally used as a fuel, the energy density is 10.2 MJ/L.

Hydrogen can be produced through steam reforming of natural gas, oil, coal or biomass. It can also be manufactured through electrolysis of water. "Green", renewable or bio-based hydrogen can only be produced from steam reforming or biomass fired electricity generation, or by using other renewable electricity sources like hydro-power, wind, solar, geothermal or wave energy.

Hydrogen releases no GHG at end use, but current production methods are energy and carbon intensive. Hydrogen is looked to by clean energy enthusiasts for energy storage potential, enabling intermittent renewable energy sources to store energy for use on demand.

3.2.3 BIOFUELS OVERVIEW

There is a strong global push to develop biofuels alternatives to the fossil fuels that dominate today. Europe and the US are advanced in their investigations of biofuels, with the US preferencing ethanol and Europe biodiesel. Neither has found great success so far in mitigating their need for crude oil imports. Table 5 shows a comparison of what the US Department of Energy considers the most viable liquid fuels. It should be noted that these are the optimistic end of values for ethanol and butanol based on recent technologies. The petrol, diesel and biodiesel prices are from Australian sources.

TABLE 5: COMPARISON OF MOST VIABLE FUELS (ABARE, 2009B; RAMEY & YANG, 2004; WILLIAM J RYAN & MICHAEL L POOLE, 2008; USDOE, 2009A)

Fuel	Energy Density (MJ/L)	Relative to Fossil Equiv. (%)	Yield (L product per t Feed) (L/t)	Pre-tax Cost (\$/L)
Diesel	38.6	100%	320	0.87
Biodiesel	37.3	97%	1136	1.34
Automotive Gasoline (Petrol)	34.2	100%	490	0.82
Ethanol	23.4	68%	227	0.70
Butanol	29.2	85%	492	0.32

The greenhouse gas advantage of biofuels is a key driver, yet cannot be given a simple figure at this stage. Table 6 is from the US Environmental Protection Authority, and shows

the difficulty in giving a single figure on greenhouse gas mitigation. Some sources of ethanol fuel may even increase emissions.

TABLE 6: ETHANOL GREENHOUSE ADVANTAGE FOR DIFFERENT TIME HORIZON AND DISCOUNT RATE APPROACHES (USEPA, 2009)

Fuel Pathway	100 year, 2% Discount Rate	30 year, 0% Discount Rate
Corn Ethanol (Natural Gas Dry Mill)	-16%	5%
Corn Ethanol (Best Case Natural Gas Dry Mill)	-39%	-18%
Corn Ethanol (Coal Dry Mill)	13%	34%
Corn Ethanol (Biomass Dry Mill)	-39%	-18%
Corn Ethanol (Biomass Dry Mill Combined Heat/Power)	-47%	-26%
Soy-Based Biodiesel	-22%	4%
Waste Grease Biodiesel	-80%	-80%
Sugarcane Ethanol	-44%	-26%
Switchgrass Ethanol	-128%	-124%
Corn Stover Ethanol	-115%	-116%

3.2.4 BIOFUELS CONCLUSION

There is huge demand for replacements for traditional fossil fuels in transport. The drivers for this demand include oil scarcity, greenhouse gas emissions, energy security, price competition, and diversification in agricultural production.

There are strong moves away from the use of food crops because of sustainability and land use concerns, but also because of the vulnerability of fuel production to the fluctuations often seen in the markets for food crops.

New technologies are making the move away from food crops to lignocellulosic crops a reality. In Wheatbelt W.A. these woody biomass crops have great potential to be combined with traditional broadacre farming, producing energy and addressing land degradation issues, without compromising food production.

Biofuel production will need to need to develop with some key guidelines in place optimising:

- Energy content to ensure that the fuel is effective in established transport infrastructure (needs to be an effective replacement for gasoline without major investment by user)
- Lifecycle greenhouse gas mitigation (both Europe and the US are introducing minimum required improvements on fossil fuel emissions for biofuels)
- Sustainability in cultivation of biomass feedstocks and avoidance of the production of toxic or wasteful production streams

Above all, to be successful in the goal of providing a viable alternative to fossil fuels, biofuels must be quality controlled and price competitive with those fossil fuels.

Other products of biomass conversion have established and emerging markets. Waste management issues and environmental damage due to long-lived, oil based plastic polymers are being addressed by development (or re-discovery) of biodegradable plastics.

3.3 BIODEGRADABLES

Demand for biodegradable replacements for petrochemical products (plastics, lubricants, solvents) is driven by:

- Toxicity of petrochemical versions (particularly when burnt)
- Benefits for waste management in terms of reduced longevity of products, and breakdown into forms from which energy can be recovered (by digestion, burning etc.)

3.3.1 BIOPLASTICS

In 2002, Australia produced around a million tonnes of plastic, and imported another 600 kilo tonnes. A third of this was used in packaging, including the 6 billion plastic bags used by Australians that year. (NOVA, 2002)

Some of the earliest plastic films were made from plant materials. Cellophane's name betrays its cellulosic origins (Carlisle, 2004), as does the name of Australia's favourite floor covering of the 50's and 60's: lino, a plastic-like sheeting made from linoleum oil and sawdust. (Powell & Svendsen, 2003) But these products were progressively marginalised as crude oil was plentiful and cheap plastics feed stock after the Second World War.

Burning of waste from households is common practice the world over. In some countries, plastic waste is used as a fuel. Burning of mixed waste with plastics that contain (such as the very common poly-vinyl-chloride, known as PVC) in this way releases dioxins (highly toxic substances related to the Agent Orange toxin used in the Vietnam War). The US Environmental Protection Authority has maintained a concerted effort over the last 20 years to reduce the amount of open air burning in that country. (Lemieux, Lutes, & Santoianni, 2004)

The use of biodegradable plastics allows for a far more effective approach to waste management. There are bio-plastics that are not degradable in the short term (soy polyurethanes and biofibre composites), but these too can be processed safely and with a useful outcome. Figure 3 shows the range of options for dealing with bio-plastics after use.

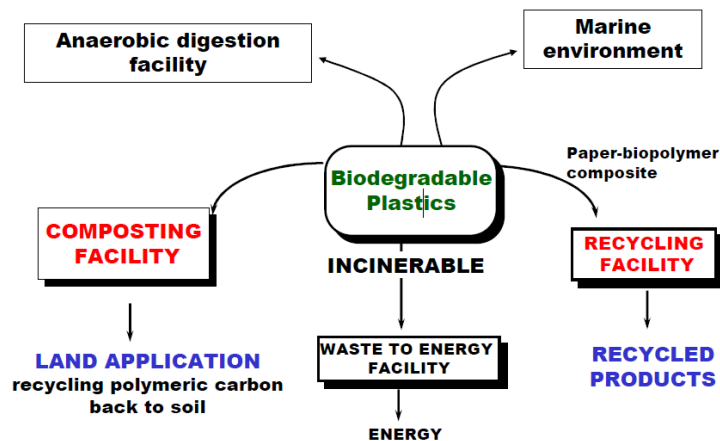


FIGURE 3: INTEGRATION OF BIODEGRADABLE PLASTIC INTO THE WASTE DISPOSAL INFRASTRUCTURE (NARAYAN, 2006)

Processes that can build monomers (the building blocks of plastics) from biomass sources have introduced a large range of biodegradable and bio-plastic products. (see Figure 4)

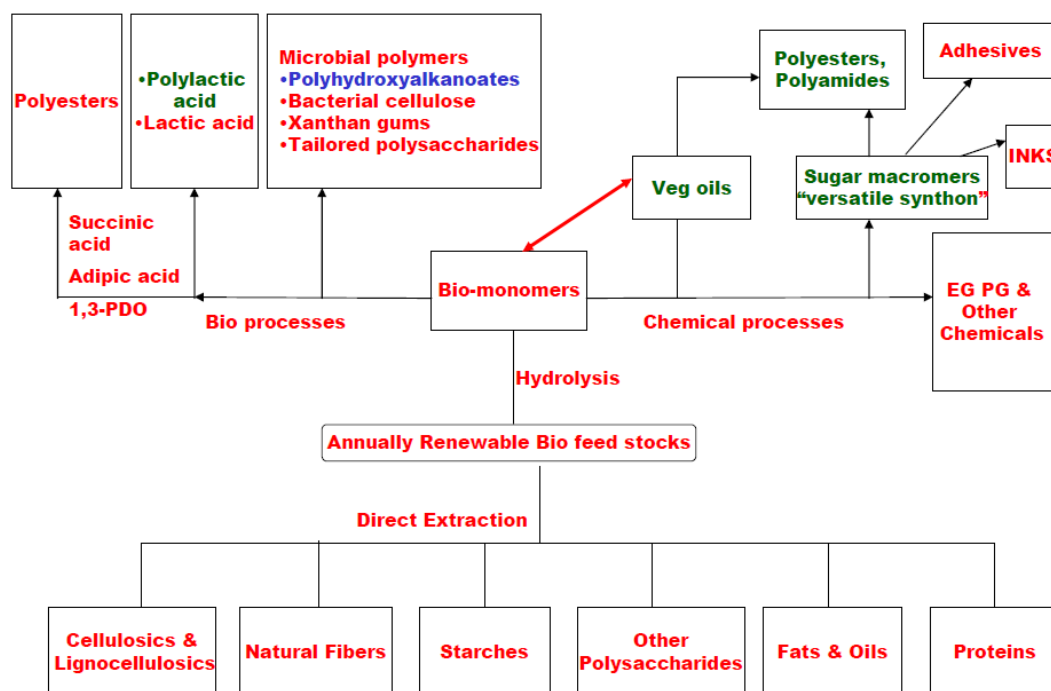


FIGURE 4: PRODUCT PATHWAYS FOR DIRECT BIOMATERIALS AND/OR BIOPLASTICS (NARAYAN, 2006)

The Australian Government has released numerous statements in favour of degradable and biodegradable plastics. (Nolan-ITU & DEWHA, 2007) Standards Australia is developing standards for the range of degradable plastics, and in 2006 released the AS4376–2006 Biodegradable plastics – Biodegradable plastics suitable for composting and other microbial treatment. (SAI, 2006)

Packaging dominates the non-construction waste that goes to Australian landfills. Innovation in the plastics sector to give this waste a safe, useful end purpose would be a significant contribution to the Australian environment. Key factors for a successful bio-plastic packaging product include:

- Compliance with the Australian Standard
- Equivalent utility to the product being replaced
- Minimal, or zero toxic or greenhouse emissions in production, use and disposal
- Low cost for bulk use materials

3.3.2 EXAMPLES OF BIOPLASTICS

Bio-plastics are mostly based on polymers that can be isolated from different parts of a plant's anatomy, particularly the hemi-cellulose and the cellulose parts.

3.3.2.1 BIODEGRADABLE STARCH-BASED POLYMERS

Starch-based biodegradable plastics may have starch contents ranging from 10% to greater than 90%. Starch based polymers can be based on crops such as corn, wheat or potatoes.

Biodegradation of starch based polymers is a result of enzyme action on glucose linkages between the sugar groups leading to a reduction in chain length and the splitting off of sugar units (monosaccharides, disaccharides and oligosaccharides) that are readily utilised in biochemical pathways. At lower starch contents (less than 60%) the starch particles act as weak links in the plastic matrix and are sites for biological attack. This allows the polymer matrix to disintegrate into small fragments, but not for the entire polymer structure to actually biodegrade. These are *degradable* plastics.

There are several categories of biodegradable starch-based polymers including:

- Thermoplastic starch products contain up to 90% starch and find wide application in plastic bags, wrap, flushable sanitary items, and mulch film that can be ploughed into the earth after use
- Starch synthetic aliphatic polyester blends are adapted to plastic sheeting with up to 50% starch content used mainly because it is cheaper than the polyester component
- Starch PBS/PBSA (poly-butylene materials) polyester blends are also mixes, using up to 30% starch with minor reduction in the strength of polyester but little reduction in workability
- Starch PVOH (poly-vinyl-alcohol) blends are used to make closed cell porous packaging products (typically loose fill 'foam' pellets) which break down in water after a few minutes

(Nolan-ITU & DEWHA, 2007)

3.3.2.2 BIODEGRADABLE POLYESTERS

Polyesters play a predominant role as biodegradable plastics due to their potentially hydrolysable ester bonds. Biodegradable polyesters are mostly formed by microbial or enzymatic actions on sugars and fatty acids. Biomass based biodegradable polyesters which have been developed commercially:

- PHA Polyesters (Poly-hydroxy-alkanoates) are produced by a microbial process, acting on a sugar-based medium. The polymer actually accumulates in the

microbe's cells during growth and the plastic is formed of microbes. No toxic by-products are known from this process.

- PHBH Polyesters (Poly-hydroxybutyrate-co-polyhydroxyhexanoates) resins are one of the newest type of naturally produced biodegradable polyesters. The PHBH resin is derived from carbon sources such as sucrose, fatty acids or molasses via a fermentation process. Besides being completely biodegradable, they also exhibit barrier properties similar to those exhibited by ethylene vinyl alcohol.
- Polylactic acid (PLA) is a linear aliphatic polyester produced by poly-condensation of naturally produced lactic acid or by the catalytic ring opening of the lactide group. Lactic acid is produced (via starch fermentation) as a co-product of corn wet milling. PLA is often blended with starch to increase biodegradability and reduce costs. However, the brittleness of the starch-PLA blend is a major drawback in many applications. To remedy this limitation, a number of low molecular weight plasticisers such as glycerol, sorbitol and triethyl citrate are used. PLA is not used in contact with food because of its fermentation manufacturing method.

(Nolan-ITU & DEWHA, 2007)

There are sought after products that can only be sourced (without great difficulty) from biomass raw materials.

3.4 BIOMASS UNIQUE PRODUCTS

These are products that have established, or emerging markets in their own right, rather than as replacements for petro-chemical products. There are many well known, as well as many lesser known products that are derived directly from biomass. Wood is an obvious example!

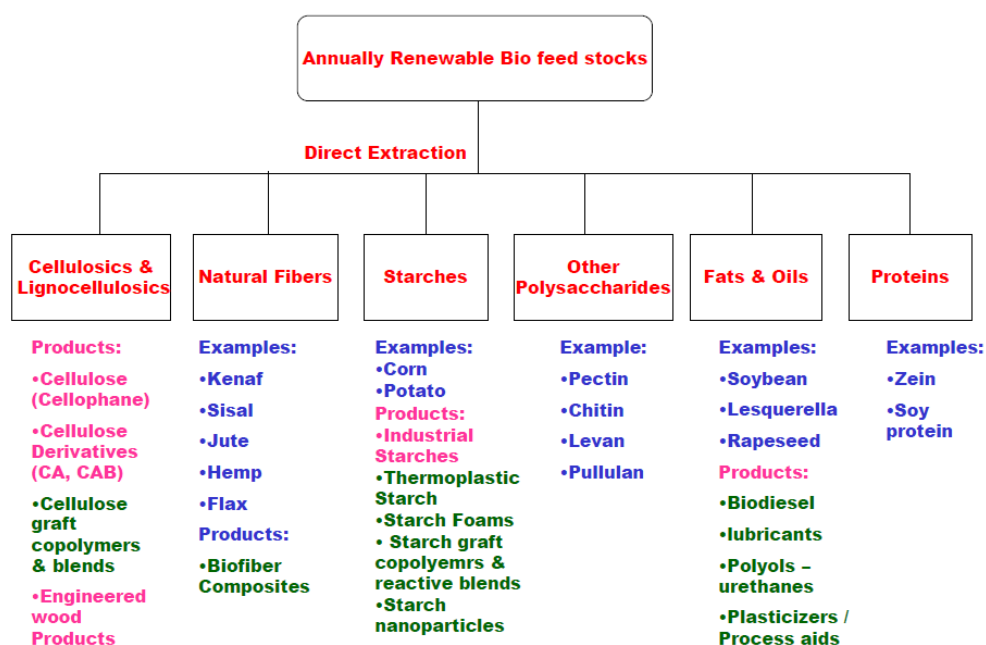


FIGURE 5: BIOMASS FEEDSTOCKS AND PRODUCTS THAT ARE BOTH DIRECTLY EXTRACTED AND DERIVED (NARAYAN, 2006)

One set of derived biomass products has a long history. The oilseed on which Canola is based, Rape, is very bitter and was originally used for production of steam engine lubricant. Traditional grease lubricants are a valued set of by-products from petrol refining. Similarly, biolubricants are mostly being produced by biodiesel manufacturers.

3.5 BIOLUBRICANTS

Biomass based lubricants are attracting interest for reasons that include:

- Biodegradability (particularly for total loss applications, where the lubricant disperses into the environment under normal use)
- Cost effective production
- Value improvement in the biofuel production chain

Table 7 shows estimates for potential market share in the US, based on information from the US department of Agriculture. The Australian market estimate is based on 13.5 million vehicles registered in Australia in 2003 compared with 237 million in the USA. (ABS, 2003; USDOT, 2009)

TABLE 7: ESTIMATED MARKET FOR BIOLUBRICANTS IN THE USA (JOHNSON, 2000)

Oil Use	Market (1,000 metric tonnes)	Probable market Bio equivalent	% Australian Market (1,000 metric tonnes)
Crankcase	3,900	24	53.3
Hydraulic	721.5	60	24.7
Marine	189.3	75	8.1
Turbine	144	20	1.6
Two Cycle	68.2	20	0.8
Drip Oil	48.8	65	1.8
Metal Cutting	12.4	30	0.2
Bar Chain	8.1	60	0.3
Wire Rope	6.5	70	0.3
Rail Flange	3.2	55	0.1
Dust Control	3.2	30	0.1

Other products of interest include adhesives, composite materials, fertilizer, and soil enhancers.

3.6 ADHESIVES

Adhesives are yet another large product group that is dominated by petro-chemical derived materials. Biomass based adhesives are most often produced by releasing, and unfolding proteins in biomass using water and modifying agents. The unfolded proteins have an amplified surface area, with many interacting side chains on the molecules, improving adhesive strength. (Sun & Wool, 2005)

A specialised stream of bioadhesives is used in surgical applications. Surgeons are constantly seeking new ways to repair tissue and assist healing. Adhesives that are safe for use in the body, and that will break down safely once their work is done, make surgery quicker and safer. The Bioadhesives Project at the Molecular and Health Technologies Centre of CSIRO is progressing research in this area. (CSIRO, 2007)

3.7 OTHER PROTEIN PRODUCTS

Plant proteins are widely used as major ingredients for food, feed, pharmaceuticals, nutraceuticals (food additive health products), paper coating, and textile sizing (smoothing of threads before weaving into fabric). (Sun & Wool, 2005)

3.8 COMPOSITE MATERIALS

Particleboard is made of wood fibre and formaldehyde glues. Given that plant proteins can be used to produce adhesives, there is good potential for producing fibreboard completely from a biomass resource such as agricultural residues, which contains proteins and fibre. (Sun & Wool, 2005)

Experiments have done with creating cement based fibre boards from the mallee eucalypts that are being farmed in the Wheatbelt. Tests concluded that mallee based board gave inferior performance compared to radiata pine chips, or other commercial options. (Semple, Cunningham, & Evans, 2002)

3.9 BIOCHAR AND OTHER SOIL CONDITIONERS

Some sources suggest that biochar can be used directly to substitute for nitrogen based fertilizers. Others are more wary; pointing out that biochar from a given source contains many residues from the original biomass.

The ash that remains from the combustion of biomass contains most of the inorganic components of the feedstock, particularly minerals and trace elements. This ash, combined with any remaining charcoal, forms a biochar. Biochar is thought to be a potent soil improver. Today, *biochar* generally refers to the solid remnant of pyrolysis, after the bio-oil and biogas are removed.

Biochar enthusiasts often refer to the famous ‘Terra Preta’, the dark soil found at some ancient sites in the Amazon regions. Humans have been adding charcoal and organic matter to their farming soils for thousands of years, creating deep layers of dark, nutrient rich soil. It seems likely that industrial biochar from biorefineries will have the same benefits for soils but scientists urge caution. Certain minerals may be concentrated in the biochar and effects are not well understood, certainly not understood for all possible feedstocks. (Bellamy, 2009)

Biochar economic value could be assessed by considering the nitrogen content, and using this to replace nitrogen from commercial fertilizers.

Biochar nitrogen content is approximately 5% (Özçimen & Iu, 2003), 11% that of Urea (46% N). Urea price varies greatly, but is expected to settle at around \$700/t over the next year. (Pivot, 2005) On this basis a fertilizer value of \$77/t can be placed on biochar. Of course there are likely to be other benefits from the other trace elements in biochar.

Another possible utilization of biochar is in compensation to growers for loss of nutrients when biomass is removed from their land. Crop residues have 0.32%/wt nitrogen content. (McNeal, Boatwright, Berg, & Watson, 1968; Tobiasen & Stein, 2002), so for every tonne of crop residue removed, 64kg of biochar would be returned to the grower.

A final valuation would need more knowledge of the particular feedstock. It would be of high importance to the sale of biochar that it could be produced with consistent characteristics.

3.10 PRODUCTS AND MARKETS CONCLUSIONS

Markets exist for biomass based products in terms of unique new products, and in replacing petro-chemical sourced products. To be a viable replacement for an established product some key guidelines have been established including:

- Compliance with any Australian Standard that may apply (now or in the near future)
- Equivalent utility to the product being replaced (performs similarly to the product being replaced, including energy content for fuels)
- Minimal, or zero toxic or greenhouse emissions in production, use and disposal (based on Life Cycle Analyses)
- Sustainability in cultivation of biomass feedstocks and avoidance of the production of toxic or wasteful production streams
- Cost equivalence to product being replaced
 - low cost for bulk use materials such as packaging
 - bioenergy product prices may be somewhat higher than current products without being seen as completely unviable because of expectations already in the market place that there is a premium on *environmentally friendly* products

Food is the prime motivation for current crops but, even without new biomass specific crops, there is potential for improving the value from a given harvest. Every component of the plant's structure has potential to be converted into a useful product:

- Oils have direct application as lubricants, and may be converted into biodiesel
- Plant fibre can be used in materials manufacture, including composite board, or more refined fibre fabric materials
- Carbohydrates in the form of sugars (saccharides) can be fermented for production of alcohol fuels
- Carbohydrates in the form of cellulose and hemi-cellulose can be hydrolysed to saccharides, and then fermented for alcohol fuel production, or can be extracted to make biodegradable plastics

- Carbohydrates in the form of ligno-cellulosics are the subject of intensive research efforts, and will soon be available for fuel production, and other processes
- Proteins have many industrial application including for adhesive production
- Combustion of plant material releases energy and produces ash and charcoal, which have soil improvement applications
- Some combustion techniques produce syngas, biogas, and pyrolysis oil, which all have fuel and energy applications

Wheatbelt WA has the potential to tap into some of these markets to improve value extracted from crops and to diversify economic activities in the region. Rather than trying to make a process viable by meeting any one of these markets, it is envisaged that a facility that includes a number of inputs, conversion processes, and outputs will have great advantages in being able to efficiently maximize value of resources, and trial and commercialise new processes at low risk. The following section examines some of the technologies that exist to produce for the markets that have been discussed.

4 TECHNOLOGIES

This chapter presents a survey of technologies with potential for integration into a biorefinery, and into a biomass based industry hub. These are processes that either involve biomass conversion directly, or are somehow adapted to integration with such processes.

Biomass conversion is performed to produce one or more of three main product types: Biofuels, bioenergy (heat and power), and chemical feedstocks. The evolution of processes to meet demands for these products is seen as occurring in three distinct technological generations.

First generation technologies are those that are mostly already in play. Production of biodiesel by transesterification of lipids (such as canola oil), production of ethanol by fermentation of sugar crops, and production of soap from olive oil, and combustion of agricultural wastes to produce heat and power, can all be considered first generation processes. These all have great potential in transitioning the economy away from oil and petrochemicals, but will have a limited long term impact in Australia unless significant new sources of oil, sugar, and starch can be found.

Second generation processes will be based on lignocellulosic feedstocks. The lignocellulosic part of a plant is the structural, *woody* part. This is the part of the plant where cellulose, hemicellulose, and lignin are tied up together, and are more resistant to being chemically unlocked to make useful products. As these processes develop, the range of biomass feedstock that can be used expands considerable, and the scale of production can be greatly increased. The potential of these processes relies on a reliable supply of well priced, sustainably produced biomass, and on minimizing capital and operating costs.

Third generation biomass technology is exemplified in the biorefinery. Much higher levels of resource efficiency are achieved by a closed loop approach in which every part of biomass input is utilized and contributes to the outputs. Full use of available biomass resources is achieved by producing not only fuels and energy, but also high value chemicals and other useful products. There is good potential for sustainable operation of a third generation because of diversification of both inputs and of products. Third generation biofuel production may also imply processes that involve reforming gases to form fuels to specification.

(McKendry, 2002; O'Connell, 2008)

These conversion processes are of three broad process types: thermo-chemical, biochemical/biological, and direct extraction. These three process categories should be explored first, before looking at specific processes that are available or emerging.

4.1 THERMO-CHEMICAL PROCESSES

4.1.1 COMBUSTION

Direct combustion is possible with any biomass because the elements that form the bulk of any plant's structure, cellulose, sugars, and lipids, all combust readily. In practice, the moisture content determines the viability of direct combustion. Moisture content above 50% generally needs drying or can be used in alternative processes like anaerobic digestion. Products of combustion are ash (the non-combustible part of the biomass), heat, and hot exhaust gases. If combustion occurs in a steam boiler then the heat can be distributed and used to do useful work (like driving a steam turbine generator). See Figure 6.

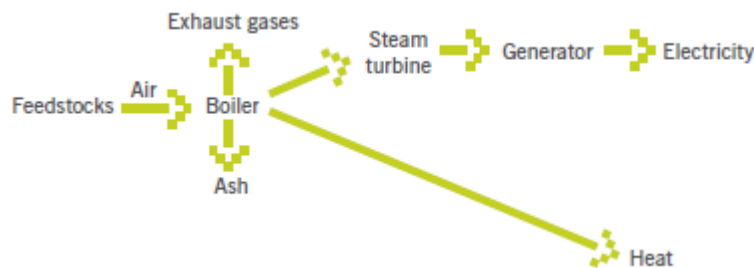


FIGURE 6: DIRECT COMBUSTION (CEC, 2008)

Co-firing of biomass involves combining a fraction of biomass with the main fuel, usually coal. This is a common practice and was taking place at the coal fired power station in Collie, W.A., until recently. The waste from a co-located pine board manufacture was fed to boilers in the coal fuel stream.

Combustion gases are released at 800-1000°C. Conversion of biomass to electricity by combustion and steam production has efficiencies 20-40% (tending to improve with the size of plant). (McKendry, 2002)

Combustion includes several phases of biomass conversion, each of which has become a separate conversion technology in its own right.

- Drying begins at temperatures of less than 100°C. Wood with moisture content higher than 60% (wet basis) will not combust effectively.
- Pyrolysis is described as thermal degradation (devolatilization) in the absence of oxygen. Pyrolysis produces tar, charcoal, and low molecular weight gases. This process begins at around 200°C, and is mostly complete once temperature has reached 400°C.
- Gasification occurs where there is an oxidizing agent available (such as oxygen in the air surrounding a burning piece of wood). Temperatures will be 800-1100°C.
- Combustion occurs as the products from each stage are completely oxidized and released as hot gases (mostly CO₂) at 800-1100°C.

In batch burning (such as a wood stove) there is considerable overlap between these phases. In continuous combustion operations such as boilers with moving grates, these phases will occur at different points along the grate. (Loo & Koppejan, 2008)

These phases will be examined as separate technologies, along with Liquefaction (thermo-chemical conversion of biomass to produce liquid fuel), and compacting biomass to improve it as a combustion fuel.

4.1.2 PYROLYSIS

Pyrolysis is a process that produces multiple streams of products, the ratios of which can be controlled by adjustments to fuel type, temperature, pressure and reaction time. The main products are biochar (carbonaceous charcoal), tar (a heavy liquid remnant known as pyrolysis oil, or bio-oil), and biogas (low molecular weight gases combined with CO and CO₂). (Loo & Koppejan, 2008)

- Biochar can be used as a fuel for cooking fires or barbeques, or may be converted into activated carbon (used in large amounts in metallurgy) by further processing in a kiln. Considerable work is being done on the use of biochar as a soil improver to offset fertilizer use, but there remain questions about effectiveness and about the effects of trace elements from the biomass that may be concentrated in the char. The char contains much of the carbon from the biomass, so working into the soil could prove an attractive means for mitigating emissions from bioenergy operations.
- Pyrolysis oil can be burnt directly for heat and power, or it can be modified to form a high grade liquid fuel.
- Biogas produced during pyrolysis can be burnt for heat and power, or can be synthesized to produce methanol or ammonia.

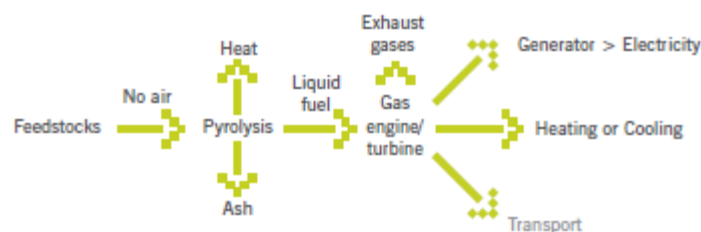


FIGURE 7: PYROLYSIS (CEC, 2008)

There are two main types of pyrolysis:

- Fast pyrolysis typically takes place in a second or less and can achieve up to 75% conversion of the dry biomass to a liquid fuel. The balance of the biomass is converted to char and biogas.
- Slow pyrolysis produces mainly biogas and char, plus some liquids.

Fast pyrolysis has been demonstrated commercially over a number of years in Canada. It is achieved by heating finely ground biomass material to 350-500°C for a few seconds. Slow pyrolysis usually occurs at 450-550°C, and has been in operation at many locations for many years as the first step in the production of activated carbon.

Although attracting local and international investment, pyrolysis has not yet achieved the same level of broad-based commercial viability as direct combustion or anaerobic digestion.

(CEC, 2008; Loo & Koppejan, 2008)

4.1.3 GASIFICATION

While pyrolysis is generally optimized for biochar or bio-oil production, gasification is optimized for the production of biogas. Temperatures of 800-1100°C are normal. The biogas contains CO, CO₂, H₂O, H₂, CH₄, and other hydrocarbon gases. (Loo & Koppejan, 2008)

Gasification involves the conversion of biomass into a combustible gas mixture (generally called *biogas*) by partial oxidation. Partial oxidation is achieved by heating the biomass with a limited supply of oxygen so that most of the feed stock breaks down and becomes biogas. The gas may then be burnt in a gas engine, or a gas turbine, or may be used as a transport fuel. Anaerobic digestion also involves the conversion of biomass into gas fuel at ambient temperatures, but the term gasification is generally taken to refer to the thermo-chemical process.

The oxidant used for gasification is usually air or oxygen, but CO₂ and steam are also used. Air gasification produces a gas with energy density 4-7 MJ/m³, while the gas produced in oxygen gasification can have energy density 10-18 MJ/m³ (these are normal meters cubed, meaning a meter cube at 0°C and 1 atm pressure). This biogas can be converted to methanol, or can be used in gas engines or turbines (after cleaning and drying).

Gas turbine efficiencies are around 30-40% (although new designs may achieve higher efficiency) for fuel to electricity conversion. Exhaust gases from steam turbines exit at around 500°C, and can be used for process heat.

Combined cycle systems include steam turbines, which are driven by steam that is produced from the exhaust heat from a gas turbine (which exits the turbine at around). See Figure 8. Combined cycle systems using biogas are not well proven because the heat exchange mechanisms have very low tolerance to fouling.

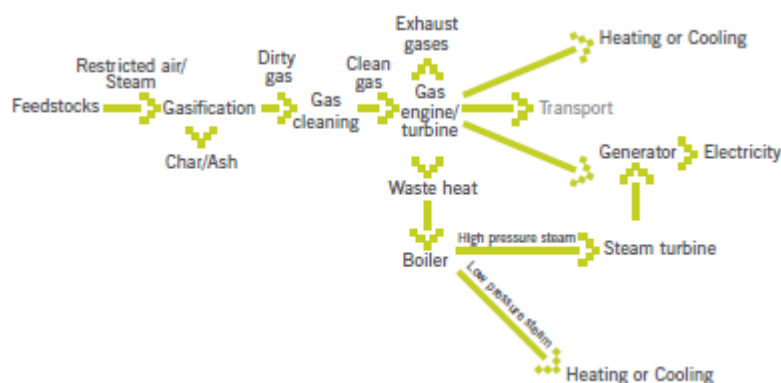


FIGURE 8: GASIFICATION AND COMBINED CYCLE (CEC, 2008)

4.1.4 LIQUEFACTION

Liquefaction is a process designed, as the name implies, to produce mainly liquid fuel as a product. It involves thermo-chemical conversion of biomass at 300-350°C and pressures of 100-200 bar, with added hydrogen and a catalyst to improve reaction rate. Fuel from liquefaction has a higher yield, and slightly higher energy content than that from pyrolysis.

Figure 9 shows the material flows in a typical liquefaction process. Interest in liquefaction is low because the gains are small for a process that is considerably more complex than pyrolysis.

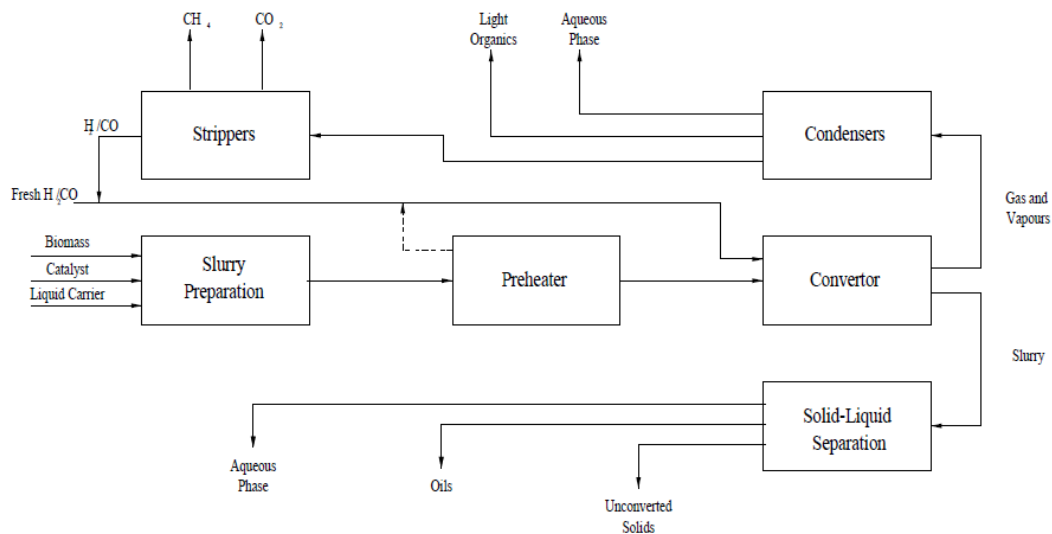


FIGURE 9: LIQUEFACTION FLOWS (MCKENDRY, 2002)

4.2 BIOCHEMICAL AND BIOLOGICAL PROCESSES

The main processes in this category are anaerobic digestion, and fermentation.

4.2.1 FERMENTATION

The most common use of the fermentation process takes sugars and converts them to ethanol using yeast. Other alcohol fuels such as methanol and butanol can be produced in fermentation processes very similar to that of ethanol, so ethanol production will be used as a model to look at this process.

Ethanol produced by the yeast in fermentation is then distilled (the most energy intensive part of the process) and used as a transport fuel or fuel additive in internal combustion engines. (McKendry, 2002) Ethanol (or ethyl alcohol, C_2H_5OH) is a clear colourless liquid, it is biodegradable, low in toxicity and causes little environmental pollution if spilt. Ethanol burns to produce carbon dioxide and water.

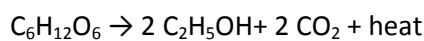
Ethanol is a high octane fuel and has replaced lead as an octane enhancer in petrol. By blending ethanol with petrol oxygenates the fuel mixture so it burns more completely and

reduces polluting emissions. Ethanol fuel blends are widely sold in the United States. The most common blend is 10% ethanol and 90% petrol (E10). This blend is now widely available in Australia. Vehicle engines require no modifications to run on E10 and vehicle warranties are unaffected also. Only flexible fuel vehicles can run on up to 85% ethanol and 15% petrol blends (E85), but this blend is becoming more common overseas. (CSR, 2001)

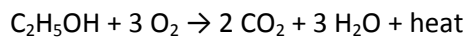
The simplest ethanol cycle starts with photosynthesis producing glucose from water, CO₂, and light:



Large sugars, like Sucrose, are converted to Glucose, which is then converted to ethanol by yeasts:



Finally, ethanol is combusted to form water, CO₂, and heat:



These reactions can be condensed to the form: light → heat.

First generation ethanol production has been overwhelmingly based on sugar cane as a feedstock, with some plants using sugar beet. Starch crops (especially maize) are also be used as feed stocks. Starch biomass is ground and treated with enzymes to break the starch molecules into sugars, which then proceed to the yeast treatment. The residue from ethanol production is the woody (lignocellulosic) part of the plant, which can then be processed further. In ethanol processes based on sugar cane, the residue (bagasse) is used to power the distillation process by combustion or gasification.

First generation ethanol production in Australia would use the course grain crops: wheat, barley, and oats. Assuming that the export fraction of these crops could be directed to fuel production (leaving the rest for current domestic uses like food production), and allowing for the lower energy value of ethanol compared to petrol, upper limits of 11-22% of Australian petrol usage could supplied by ethanol. (O'Connell, 2008)

Second generation ethanol production will be based on breaking down the lignocellulosic part of the plant, as well as the more accessible starches and sugars. Some bio-catalytic processes show promise and will be discussed.

4.2.2 ANAEROBIC DIGESTION

Anaerobic digestion (AD) is a well proven technology that is applied to biomass feedstocks with high moisture content (usually above 80%). A micro-organism converts organic material to a biogas comprised mainly of methane and CO₂, leaving a slurry of remnant material that can be further treated by composting and aerobic processes to output (ideally) only water. A typical set of AD process flows is shown in Figure 10.

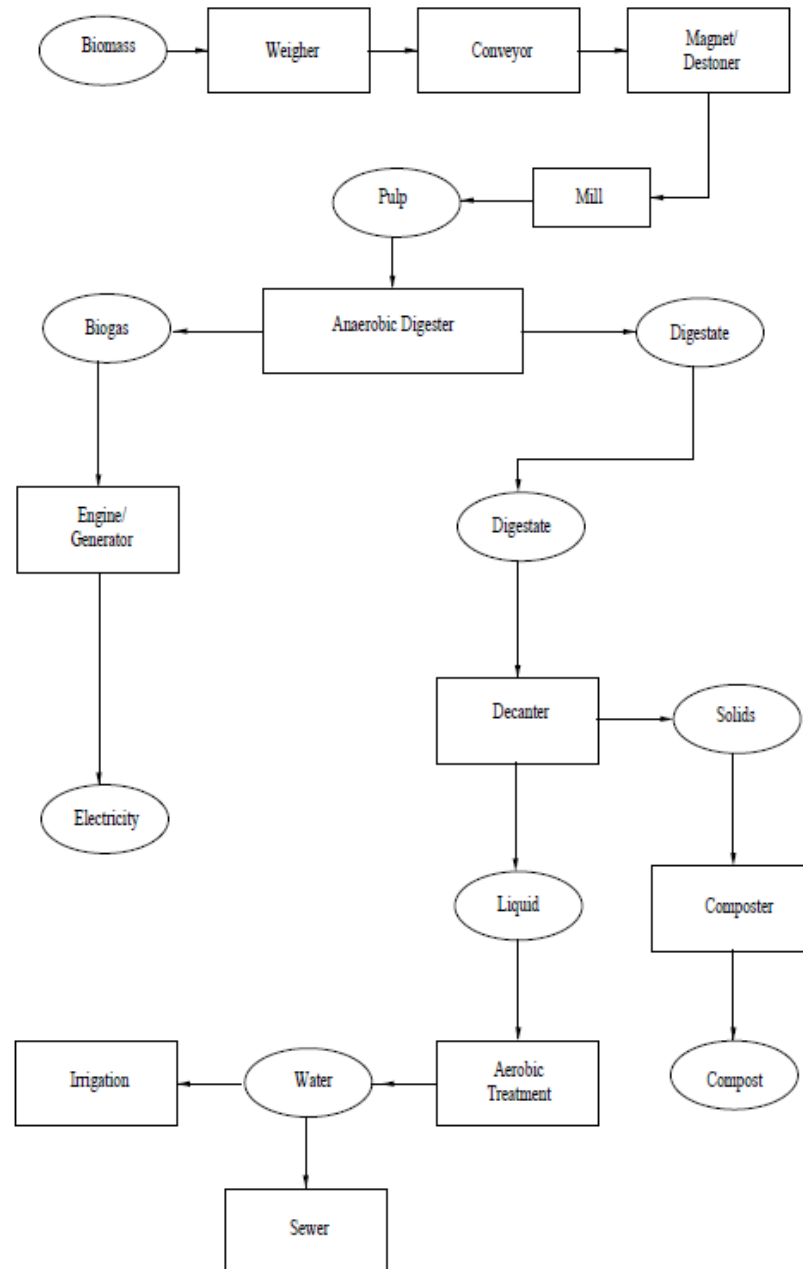


FIGURE 10: ANAEROBIC DIGESTION PROCESS FLOWS (MCKENDRY, 2002)

Overall efficiency from biomass feed stock to electricity generation is 10-16% using anaerobic digestion to produce gas to fuel a gas engine. Gas engines produce heat that could potentially be captured for process heat applications. (McKendry, 2002)

4.3 MECHANICAL AND NON-BIOLOGICAL CHEMICAL PROCESSES

The mechanical and non-biological chemical processes that should be considered in the context of biomass conversion are essentially about oil extraction and subsequent production of biodiesel. Non-biological chemical processes are intended as those processes which do not involve micro-organisms, such as esterification and solvent extraction.

4.3.1 BIODIESEL

Diesel engines are capable of burning unprocessed vegetable oil, if the viscosity is sufficient. This can be achieved by heating the oil on its way to the diesel injector pump, but more often the oil is modified to produce *biodiesel*.

Oil seeds are crushed and the oil content removed by cold pressing, pressing at higher temperatures, or by solvent extraction. The residue from crushing is known as *meal* or *seed cake*, and is a valued stock feed. Higher oil content in meal increases its value, so the degree oil extraction from seeds is tuned to leave the desired amount of oil in the meal depending on the specific economics in play.

The extracted oil is then treated by a process known as transesterification to improve viscosity. The oil is mixed with an alcohol (often methanol) and a catalyst (often sodium hydroxide), and reacts to form methyl esters (biodiesel) and glycerol. (NBB, 2009)

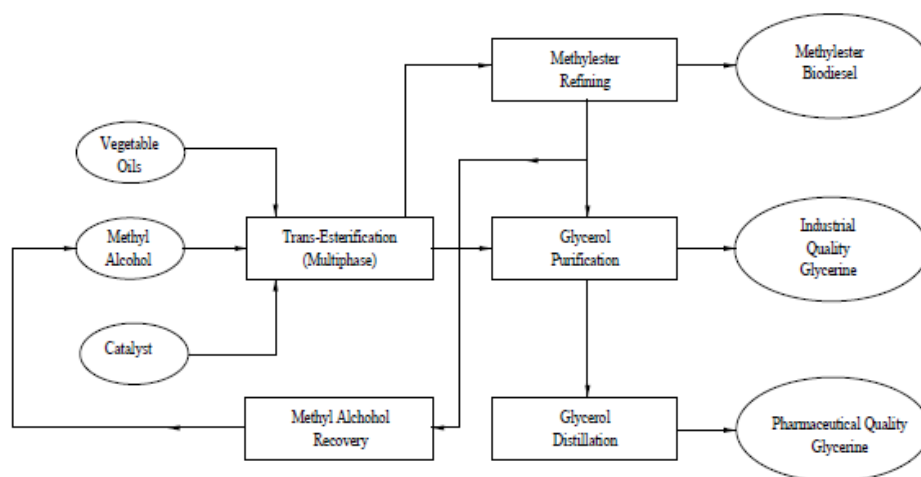


FIGURE 11: ESTERIFICATION PROCESS FLOWS FOR BIODIESEL (MCKENDRY, 2002)

Biodiesel is defined (in Australia) by the Fuel Quality Standards Act 2000 as “a diesel fuel obtained by esterification of oil derived from plants or animals” and is regulated by the Fuel Quality Standards Act 2000, the Fuel Quality Standards Regulations 2001 and the Fuel Standard (Biodiesel) Determination 2003.

(Department of Environment, 2009)

4.3.2 COMPACTED BIOFUEL

Bioenergy from combustion has been the subject of considerable technological optimization, particularly in Scandinavia. One of the outcomes has been the development of stoves and burners that use pelletised biomass as a feed stock. The small, predictable unit size of the pellets allows for automated control of the firebox (where the combustion occurs) to optimize energy conversion and emissions.

While not a conversion technology in the same sense as the other processes described, the pelletisation of biomass can supply high efficiency heaters and can be used more easily

than raw biomass for co-firing with coal. Torre-faction may also be employed to increase the energy density of the pellets. Torre-faction involves heating the material to around 200°C (where pyrolysis begins) to reduce moisture content and to activate the pyrolysis oils. The result is a pellet that resembles coal (brown to dark brown in colour, hydrophobic), and has an improved energy density of 15-18.5 GJ/m³. (Bergman & Kiel, 2005)

The existence of a reliable supply of suitable pellet fuel will make investment in high efficiency combustion more viable. There are a number of fuel pellet producers in Australia, including

- Western Australia based Plantation Energy have approval for wood pellet plants at Wandilo, South Australia, and at Heywood, in Victoria, which will both utilize Blue Gum plantation wastes and create pellets mainly for export at this stage (ABC, 2009a, 2009b) but the company hopes to develop a local market, starting with co-firing pellets with coal
- Plantation Energy already have a Pellet Plant operating at Mirambeena Industrial Park, with a new terminal being constructed at nearby Albany Port for export of a predicted 250000 T/yr of the pellets to Europe

There are already a number of operators in Wheatbelt W.A. who are creating pelletised food for animal feed, and could probably modify their operations to produce wood pellets with relatively little capital expenditure.

- Macco Feeds in Williams
- Gilmac (Mackie Hay) in New Norcia

The ability to make fuel pellets from other feed stock than wood, particularly from municipal green waste and from agricultural residues (as identified in the Resources section of this study) would be particularly interesting at these locations.

Equipment

Pellet mills are a well developed technology, available from numerous manufacturers.

Austrian manufacturer Andritz AG distribute pellet mills in Australia. Andritz claim that their mills produce wood pellets using approximately 2.5-3% of the energy content of the feed stock. (Andritz, 2009)

4.3.3 BIOETHANOL PRODUCTION

Ethanol is produced by fermentation of sugars using yeasts (micro-organisms containing enzymes that catalyze the conversion reaction from sugars to ethanol). When biomass with large fractions of cellulose and hemi-cellulose is used (most often the case), pre-treatment to break the cellulosic material into sugars (saccharification) is necessary for good yields. Usually lignin remains at the end of the ethanol process and may be used for further processing, or to power boilers.

Pretreatment of the cellulosic material is commonly by hydrolysis, which can be by concentrated acid, dilute acid, or by enzymes.

CONCENTRATED ACID HYDROLYSIS

Biomass is dried to around 10% moisture. 70-77% sulphuric acid is added, and the mixture is brought to 50°C. Later water is added and the temperature raised to 100°C for 1 hour. The gel that is produced is pressed to release the acid and sugar mix, and the residue is available for further processing, or for the boiler. The acid and sugar mixture is then separated using a chromatograph column.

DILUTE ACID HYDROLYSIS

Dilute acid hydrolysis is the traditional method. The first stage uses 0.7% sulphuric acid at 190°C, and hydrolyses most of the hemi-cellulose. Next the more resistant cellulose fraction is hydrolyzed using 0.4% sulphuric acid at 215°C. Each stage has a residence time of around 3 minutes. The hydrolyzates are the liquid parts at the end of each phase, which are neutralized and fermented to produce ethanol. The woody lignin residue feeds the boiler.

ENZYMATIC HYDROLYSIS

Enzymes are being developed to hydrolyze biomass into sugars. These processes represent one of the major research pushes in Biofuels. Specific developments will be discussed.

WET MILLING PROCESSES

Corn can be processed into ethanol by either the dry milling or the wet milling process. In the wet milling process, the corn kernel is steeped in warm water; this helps to break down the proteins and release the starch present in the corn and helps to soften the kernel for the milling process. The corn is then milled to produce germ, fibre and starch products. The germ is extracted to produce corn oil and the starch fraction undergoes centrifugation and saccharification to produce gluten wet cake. The ethanol is then extracted by distillation. The wet milling process is normally used in factories producing several hundred million gallons of ethanol every year.

DRY MILLING PROCESS

The dry milling process involves cleaning and breaking down the corn kernel into fine particles using a hammer mill process. This creates a powder with a coarse flour type consistency. The powder contains the corn germ, starch and fibre. In order to produce a sugar solution the mixture is then hydrolysed or broken down into sucrose sugars using enzymes or a dilute acid. The mixture is then cooled and yeast is added in order to ferment the mixture into ethanol. The dry milling process is normally used in factories producing less than 50 million gallons of ethanol every Year.

(CSR, 2001; USDOE, 2009b)

4.4 BIOMASS CONVERSION TECHNOLOGY CONCLUSIONS

Biomass conversion processes involve both well established and emerging technologies.

Apart from direct combustion, the most established processes rely on sugar, starch and oil plant components, and tend to be associated with plants that give a high yield of the

required component. An example is the trans-esterification process, which operates on lipids and consequently relies on oil rich crops like canola. Ethanol is produced from sugar and starch rich plants like sugar cane. Hydrolysis is the process of opening up a plant's structure by steeping in a mild base or acid, thereby allowing a larger range of plants, and more parts of plants, to be used for fermentation.

These sugar, starch, and oil plants have so far been predominantly food crops, which has caused problems, particularly on the social front, as people feel threatened by the encroachment of industrial resource consumption into the realm of food. Lignocellulosics (the woody parts of plants) are generally not used as food because only a few animals such as cockroaches are able to digest them. This has led to a large research and development effort to make this biomass type accessible to established processes, or to develop new processes that can work on it directly.

One process that has traditionally operated on lignocellulosics is direct combustion, which may include co-firing, and may be part of a cogeneration process (where both heat and electricity are products). Biomass pellets allow for a high degree of control over the combustion process in purpose built burners, and so the production of these pellets should be seen as facilitating improved efficiency in combustion. Direct combustion can be fuelled by residues from other processes, in turn providing energy to those processes. This approach has taken hold in ethanol production from sugar cane, and in some paper mills, and represents a simple implementation of the closed loop approach which this study proposes as a primary characteristic of a biorefinery.

Gasification and pyrolysis are the emerging developments of the combustion process. Both involve combustion in limited oxygen. Gasification produced syngas, which may be reformed with a catalyst to produce a variety of fuels. These processes cannot be considered fully commercialised. Use of the water shift process to turn the syngas into hydrogen is proven, although would not be economically viable without major changes in fuel infrastructure, and possibly commitment to a hydrogen economy. Pyrolysis produces both biogas and a heavy oil; the fractions of each can be somewhat tuned. The biogas can be combusted, as can the heavy oil. Considerable work is being done on using the oil in fuel production. Anaerobic digestion is a well proven technology that uses a microbial action to break down lignocellulosics to produce biogas and organic sludge. The rich sludge is a useful ingredient in organic soil improvers.

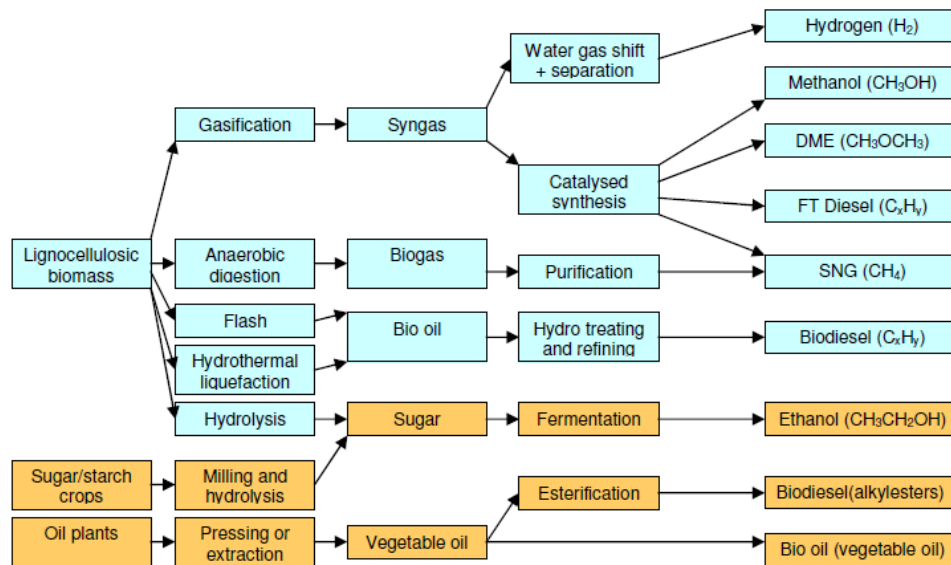


FIGURE 12: FIRST AND SECOND GENERATION BIOFUEL PATHWAYS (O'CONNELL, 2008)

Figure 12 shows a set of pathways with the three main biomass categories: Lignocellulosics, Sugar/Starch crops, and Oil Plants.

Given this range of processes, it is now possible to survey the resources available in the Wheatbelt to identify suitable feedstocks.

5 RESOURCE ASSESSMENT

Western Australia's Wheatbelt region is one of the most significant crop growing zones in the nation. Wheat predominates but many other crops and activities are present. There is a long history of European agriculture in the region but, as in so many heavily cleared and cropped zones of the world, the environmental damage from farming is beginning to have an impact on economic viability. (Farmer-Bowers et al., 2006)

The potential for biorefineries in this region is dependent upon the availability of biomass resources, the nature of these resources, and their specific economics. The types of biomass resources to be surveyed include those from agriculture, forestry, agro-forestry, and waste streams in the region.

The major biomass categories have been identified as lignocellulosics, sugar and starches, and lipids (oils). There are few biomass resources that contain one of these biomass types in a pure form. It is necessary to look at the plants and waste streams that are present in a region, and to assess each on its suitability as a feedstock for a given process type. The assessment must include both the quantity of the various useful biomass components, and accessibility of those components.

Biomass feedstocks fall into a number of basic categories.

- Cereal crops
- Oil seed crops
- Crop residues
- Process residues
- Organic waste products
- Woody biomass (energy crops)
- Forestry waste

Biomass conversion product categories need to be surveyed in the context of these biomass feedstock types, identifying which feedstock may be best adapted to which process.

5.1 BIOMASS CONVERSION PRODUCT CATEGORIES

The main categories of Biomass conversion products are associated with particular conversion processes, which in turn require particular biomass feed stock types. This list is filtered to show possible feedstocks that are more likely to be found in the Wheatbelt.

5.1.1 STATIONARY BIOENERGY

Combustion (including gasification and pyrolysis)

- Crop residues
 - Cereal crop straw

- Cereal crop chaff
- Other lignocellulosic crops
 - Annual and perennial grasses
 - Woody biomass crops (Oil mallee)
- Forestry
 - Plantation thinnings
 - Plantation residues
- Waste streams
 - Waste from wood processing facilities
 - Urban wood waste
 - Black liquor (byproduct of pulping)
 - Residues from food processing
 - Municipal Solid Waste

5.1.2 BIOFUELS

Ethanol

- First generation
 - Sugar and starch crops
 - Wheat, Barley, Oats
- Second Generation
 - Lignocellulosics (woody crops)

Biodiesel

- First generation
 - Used cooking oil
 - Tallow
 - Canola
 - Mustard
- Second generation
 - Lignocellulosics

Butanol, Methanol, Biogas

- Sugar and starch crops
- Lignocellulosics

5.1.3 BIOPRODUCTS

Lubricants

- Currently these products depend on oil from oil seed crops such as canola and mustard

Soil Improvers (e.g. Fertilizer replacements)

- Ash from direct combustion contains many of the trace elements contained in the feedstock
- Sludge from anaerobic digestion is a rich source of organics for soil improvers
- Fibre from the lignocellulosic parts of plants can be included to improve soil structure, reduce erosion, and provide a scaffold for helpful microbes in the soil

Solvents

- Many solvents are produced from butanol, which can be produced from biomass
- Hydrolysis/fermentation of starch crops is an established, but not commercial process
- More advanced is reformation of syngas with a catalyst, also not commercialised
- There are strong indications that biobutanol has a strong future as a renewable fuel with many large players investigating and patenting approaches (e.g. the partnership of BP and DuPont)

Polymers

- Biomass based polymers are produced from sugars and starches (polysaccharides), or plant cellulose
- It should be remembered that the first plastics (e.g. cellophane) were originally plant based
- Plastic polymer building requires a highly purified cellulose pulp (requiring more processing than, for example, paper pulp) and is therefore expected to be a low yield process
- Hemi-cellulose (starch) is used in 'biodegradable' plastics, sometimes as the bulk of the material, in which case the plastic can be composted, or at lower concentrations to form weak links in plastic bags made mostly from petro-chemical polymers, causing them to disintegrate more quickly after disposal

Activated carbon

- Produced by, essentially, baking organic material until a very high surface area fine charcoal evolves
- Used in metallurgy, activated carbon from coconut has always been the most highly prized, and so provides a model to be emulated when producing from other sources

5.1.4 BIOTECH

Medical and cosmetic applications

- Glycerol (by-product of transesterification process in biodiesel production)
- Biotech products may come out of research into properties of particular characteristics of particular species

5.2 BIOMASS CRITERIA

It is now possible to look at available biomass resources in the context of the general requirements of known biomass conversion processes. Quantities are required both in terms of absolute amount of a resource, and relative amounts of useful components.

Potential feedstocks will be characterised according to:

- Specific energy
- Lignocellulosic content
- Cellulose content
- Hemi-cellulose content
- Oil content
- Ash content
- Approximate cost per tonne delivered

For convenience in identification of resource opportunities, the types of resources available will be considered in a number of classes:

- Crops (wheat, barley, oats, canola and lupin are the dominant crops in WA)
- Bioenergy crops (oil mallee has been trialled, many are under investigation)
- Residues
 - Primary
 - Crop residues like chaff and straw
 - Forestry waste (plantation thinnings and residues)
 - Secondary
 - Processing residues like oat husk
 - Tallow and
 - Tertiary
 - Post-use waste that may be diverted from landfill (e.g. construction waste)
 - Municipal green waste
 - Used cooking oil

A look at each potential resource identifies the basic characteristics and quantities involved for each identified potential feedstock.

5.3 W.A. BIOMASS RESOURCES OVERVIEW

Wheat is WA's major crop, followed by barley, oats, lupins and canola. Figure 13 shows the predominance of Wheat in the crop mix, and other crops that are significant.

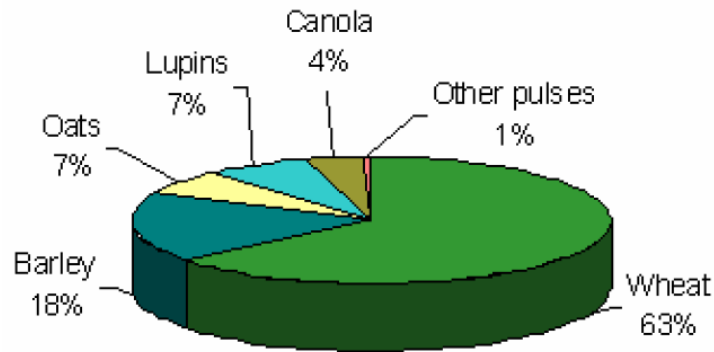


FIGURE 13: OVERVIEW OF W.A. CROPS (WILKINS, 2006)

5.3.1 PRINCIPLE CROPS ABARE CROP REPORT 2009

The principle crops grown in WA are shown in Table 8 with production data. These crops are referred to generally as *broadacre crops*.

TABLE 8: W.A. MAJOR CROP DATA

Crop	Year	Area ('000 ha)	Production (kt)	Yield(t/ha)	Domestic Price (AU\$/t av.)	Approx return (\$/ha)
Wheat	2009-10	4800	7482	1.56	276	430.215
	2008-09	4900	8915	1.82	286	520.3449
	2007-08	4528	5820	1.29	444	570.689
	5 year Average	4617	7946	1.72		
Barley	2009-10	1230	2188	1.78	235	418.0325
	2008-09	1250	2527	2.02	259	523.5944
	2007-08	1381	2719	1.97	371	730.4482
	5 year Average	1237	2415	1.95		
Oats	2007-08	280	563	2.01	389	782.1679
Lupins	2009-10	301	346	1.15	n/a	
	2008-09	267	341	1.28	261	333.3371
	2007-08	546	533	0.98	318	310.4286
	5 year Average	618	753	1.22		
Canola	2009-10	607	800	1.32	549	723.5585
	2008-09	620	1138	1.84	580	1064.581
	2007-08	595	752	1.26	648	818.9849
	5 year Average	446	555	1.24		

(A. B. o. A. a. R. E. ABARE, 2009a)

The price information in Table 8 is notional and is taken from Australian dollar domestic prices from the following market periods:

- Apr-Jun 2009
- Oct-Dec 2008
- Oct-Dec 2007

International (export) prices can vary considerably from domestic.

Given that these grains are produced as food, they will not be considered available to the biomass industry. It is expected that there will be some land competition between food crops and future fuel crops, once they begin to be established on a larger scale. This must be managed carefully, but remembering that the food producing land is currently under threat and will be compromised if agricultural systems do not change.

Hoogwijk et al. (2003) showed that the trade off may not need to be as absolute as it is sometimes cast. Table 9 shows a range of possible scenarios based on diet, population growth rate (predicted to be between low and medium), and type of agriculture. Many scenarios show the possibility of large amounts of agricultural land being available to non-food cropping.

TABLE 9: POSSIBLE EXCESS AGRICULTURAL LAND BY DIET AND POPULATION SCENARIO (HOOGWIJK ET AL., 2003)

Type of diet	Vegetarian			Moderate			Affluent		
Population growth rate	Low	Med	high	low	med	high	low	med	high
Intensive agriculture	74	72	66	52	48	38	16	9	3
Low input agriculture	26	20	3	0	0	0	0	0	0

In the case of the Wheatbelt, as noted, there will be inevitable incursion into food producing land as necessary revegetation expands. Because of this expected re-allocation of food producing land this study will assume no use of food crops.

5.3.2 BIOENERGY CROPS

There are crops being developed specifically for use in bioenergy and biomass conversion applications. The most notable example in W.A. so far is the Oil Mallee Project. Significant plantings were made to support a biorefinery pilot plant that was successfully tested at Narrogin, in Wheatbelt W.A. in 2006. This project has been mothballed but the owner, Verve Energy, is actively working to move to a full-scale commercial plant. (Conway, 2009)

The Integrated Wood Processing plant (IWP) will produce electricity, charcoal, activated carbon, and eucalyptus oil, from mallee feedstock grown on farms in the Wheatbelt of Western Australia. All four products can be produced economically by sharing the infrastructure and maximising use of the feedstock. The activated carbon technology is Australian, developed by the CSIRO.

Fully commercial plants are expected to produce the following annually, from 100,000 tonne of mallee feedstock material supplied by some 10 million mallees (OMA, 2008):

- 5 MW of electricity
- 1000 tonne eucalyptus oil, and
- 3500 tonne of activated carbon

Whilst the Mallee Project is well advanced, the species involved is not suited to all Wheatbelt soil types or conditions. The W.A. Department of Agriculture and Food has commissioned a report into other potential biomass crops for the Wheatbelt. A draft of this report will be delivered in October and will add considerably to discussions on the direction of bioenergy in Wheatbelt W.A. (Bellamy, 2009)

The State Salinity Strategy (2000) includes a plan for huge areas (in the order of 3 million hectares) of the Wheatbelt to be revegetated. This strategy could provide additional impetus to planting of woody biomass species. (Doepel, 2009)

5.3.2.1 BASIC STATISTICS

The practice with oil mallees is to wait at least 5 years before the first harvest, then harvest every 3 years. Each tree produces 15-20kg of biomass, or 38 t/ha (at standard planting density of 2500 trees per hectare), at each triennial harvest. Therefore an annual yield figure of 12.5 t/ha is used.

Approximately 14000 ha of oil mallee have been planted in Wheatbelt W.A., giving an annual production of 175 Kt. This fresh mallee is approximately 45% water, so the dry figures are used assuming that the material will have been substantially dried before use.

Accepted price point is \$15/t to the farmer. Overall price to the processor (including harvesting and transport) is expected to be around \$45/t. (Conway, 2009)

The ash of oil mallee contains numerous minerals, which could have value if extracted, or as soil additive.

The stated goal of the revegetation effort to combat salinity in the Wheatbelt is to plant 2 Mha with oil mallee, or similar.

5.3.2.2 BIOENERGY CROP DATA OVERVIEW

The existing 14kha and a projected 3Mha are assessed.

TABLE 10: FUEL CROP OVERVIEW

Area (Kha)	Yield (t/ha)	Annual Production (Kt)	Annual Production DRY (Kt)	Reference	Energy (GJ/t)	Ash (%db)	Reference	Ethanol yield (L/t)	Reference
14	12.5	175	96.25	(OMA, 2008)	20.02	1.2	(Tobiasen & Stein, 2002)	380	(Wu & Bartle, 2008)
2000	12.5	37500	13750	(OMA, 2008)	20.02	1.2	(Tobiasen & Stein, 2002)		

5.3.3 RESIDUES

Primary residues are produced during production of food crops and forest products, e.g. thinnings from commercial forestry and straw. Such biomass streams are typically available 'in the field' and need to be collected to be available for further use.

Secondary residues are produced during processing of biomass for production of food products or biomass materials, and are typically available in the food and beverage industry, saw and paper mills, etc.

Tertiary residues become available after a biomass-derived commodity has been used, meaning a diversity of waste streams is part of this category, varying from the organic fraction of municipal solid waste (MSW), organic waste and demolition wood.

5.3.4 PRIMARY RESIDUES: CROP RESIDUES

Comprising chaff, straw, dust (very fine chaff), and remnant stubble. Of these chaff and straw are harvestable. In modern broadacre cropping, the chaff is separated from the grain in the harvester, and may be collected or laid out behind the harvester as it passes. Straw is left standing or *slashed* (mowed). Straw and chaff are either left in field, burned, grazed by livestock, or collected and removed (Collins, 2005)

According the Food and Agriculture Organization (FAO), the main agricultural arm of the U.N., a reasonable estimate for *potentially harvestable residues* from broadacre crops is 1.3 tonne of residue for every tonne of grain (Rosillo-Calle, Groot, Hemstock, & Woods, 2007; UN, 1989) Other figures refer to the Harvest Index for grains, a ratio of the total above ground biomass yield. Wheat and barley are rated HI 0.43, while oats are HI 0.40 (Rowell & Young, 1997) These two approaches result in similar figures.

Because soil condition is improved by remnant organic material after cropping, there is a worldwide trend toward leaving crop residues in the field. In the US a new law has been enacted that requires 30% of organic material to remain in the field after harvesting (Sluis, Shane, & Stearns, 2006). It seems wise to anticipate a similar ruling in Australia, and to reduce potential yields of crop residue by at least 30% to 0.9 tonne per tonne of grain.

Too much residue left on the ground also has negative effects, as it can make planting the next crop difficult, can release methane if digestion begins in thick layers of material, and can slow initial plant growth (reducing yield). Consensus in the literature is that 30% of the available residue can be removed without impacting on soil quality. This is the figure that should be applied until further studies and experience suggest a change.

The resulting yield of available crop residue is 400kg/t of grain produced, composed predominantly of chaff, leaves, weeds, and dust.

The chaff fraction of the harvest (also known as the Non Grain Material, or NGM) typically has a larger hemi-cellulose fraction than the straw, or stalks of a given crop. This has been studied in Wheat and it has been shown that the chaff fraction requires less pre-processing

(enzymatic or acid hydrolysis) to produce sugars for ethanol production. Ash content is high in chaff, at 10-11% by weight (Duguid et al., 2007).

Energy content is estimated for all cereal residues as 12.77 GJ/t (UN, 1989)

Biofuel potential, expressed in terms of ethanol yield for convenience, is said to be 170L/t, based on second generation cellulosic processes. (Duguid et al., 2007)

A per tonne price is difficult to assign to crop residues. Contracts must be arranged with growers and there are no examples in the literature. The raw material will be assumed to be free, and a price given based on the cost of fertiliser needed to compensate the grower for nutrients removed from with the residue, and on the cost of transport of the material. It is necessary to consider the need to add fertilizer to compensate for biomass removed. These issues are generic to a number of potential feedstocks, and are considered in the overview section, later in this chapter.

5.3.5 PRIMARY RESIDUES: FORESTRY WASTE

Plantation pruning and thinning generates biomass. Until recently, this forestry waste was co-fired with coal in the thermal electricity plant at Collie. This practice ceased after a large explosion caused by accumulation of gummy material from the forest material.

Large amounts of forestry waste are now being shipped to Geraldton for bioenergy production. It is not clear how much of the total resource is locked in to this contract.

5.3.5.1 PRIMARY RESIDUES OVERVIEW

Co-firing at Muja Power Station in Collie had been consuming 78 Kt of sawmill residue from Pinetech annually. A new bioenergy plant came on line in 2009 at Wanneroo in Perth will require 190 Kt per year, and has an agreement with the Forest Products Commission to be supplied from plantation waste from a 100km radius of the plant. A new biomass pellet plant in Albany opened this year and is expected to consume 250 Kt of pine and eucalypt plantation waste annually.

TABLE 11: PRIMARY RESIDUES OVERVIEW

Resource	Annual Production (Kt)	Reference	Energy (GJ/t)	Ash (%db)	Ethanol Yield (2 nd gen.) (L/t)	Reference	Grower Price (AU\$/t)	Delivered Price (AU\$/t)	Reference
Crop Residues	3000	(Rowell & Young, 1997; UN, 1989)	12.8	10.5	170	(Duguid et al., 2007; Tobiasen & Stein, 2002)	5	45	(William J. Ryan & Michael L. Poole, 2008)
Forestry waste	539	(Estate, 2008)	19.6	1.8		(Tobiasen & Stein, 2002)	0	30	(Conway, 2009)

5.3.6 SECONDARY RESIDUES: PROCESSING RESIDUES

Most facilities that work with grains require the removal of the hard case around the seed, the husk, to be removed. As a rule of thumb, it will be estimated that, by weight, 25% of the incoming feedstock ends up in the hulling waste stream. (Demirbas, 2004)

A rough estimate can be made of the amount of processing waste available for immediate use by looking at the number of operators in the region that have activities likely to produce useful biomass waste streams.

Estimates of the quantities of material available can be based on the amount of raw material being processed, and verified against the figures provided by Morton Seed and Grain in Wagin.

Energy content of oat hull is 16.3 GJ/t (Fan, Marshall, Daugaard, & Brown, 2004) and range for husks and hulls is 14-21 GJ/t (Demirbas, 2004) 16 GJ/t will be used. Husks are generally very high in ash (>20%).

5.3.7 SECONDARY RESIDUES: TALLOW AND COOKING OIL

Tallow is a by-product of the animal slaughter industry and is available in W.A. from various locations. Although used cooking oil should be considered a tertiary residue, it is usually collected and resold by the same operators who distribute tallow, and so the two resources are considered together.

Bioenergy use of tallow is typically for biodiesel production. Biodiesel can be produced from tallow with '100% yield', which means that approximately a tonne of biodiesel can be produced from each tonne of tallow feedstock. Used cooking oil is another popular choice for biodiesel feedstock, particularly with smaller producers. (Grant, Beer, Campbell, & Batten, 2008)

Western Australia produces approximately 40 Kt of tallow annually, of which around 20 Kt could be available for bioenergy applications.

W.A. produces approximately 11 ML of used cooking oil each year, of which half could be available for bioenergy.

Annual Production:

Total annual resource in W.A. is approximately 25 Kt of recovered oil and fat.

Price:

Delivered price varies considerably because of the high export fraction of the market. Range is \$500-1000 /t.

Energy Content:

Energy content for tallow and for vegetable oils (including used cooking oils) is 38-40 GJ/t.

(Grant et al., 2008; WABTR & Dale, 2007)

5.3.7.1 SECONDARY RESIDUE OVERVIEW

Resource	Annual Production (Kt)	Reference	Energy (GJ/t)	Ash (%db)	Reference	Delivered Price (AU\$/t)	Reference
Process residues available	220	(A. B. o. A. a. R. E. ABARE, 2009b; Fan et al., 2004)	16	20	(Demirbas, 2004)	15	Estimate
Process residues theoretical	3000	(A. B. o. A. a. R. E. ABARE, 2009b; Fan et al., 2004)	16	20	(Demirbas, 2004)	15	Estimate
Tallow and used cooking oil	25	(Beer et al., 2002)	39	0	(Beer et al., 2002)	750	(Beer et al., 2002)

5.3.8 TERTIARY RESIDUES: MUNICIPAL GREEN WASTE

The major tertiary residue to be considered in the Wheatbelt context is municipal green waste (mostly tree prunings and lawn clippings).

Although incineration of all solid waste is possible, there are many technical, environmental, and political barriers involved. It will not be addressed in this report. Green waste, however, represents a more appealing bioenergy feedstock.

Green waste is currently land filled or burnt in most locations. A bioenergy project could conceivably take advantage of this resource by collecting it from landfill sites under an arrangement with the local shire.

5.3.9 OTHER TERTIARY RESIDUES

Manures from pigs, poultry, and humans can be problematic for disposal, but also have great potential for energy production. Anaerobic digestion is the most common approach.

5.3.9.1 TERTIARY RESIDUE OVERVIEW

Approximately 3Kt of municipal green waste is collected per year from Wheatbelt towns. (DPC, 2007) While this is a relatively small resource, it is already being collected and transported, so could easily be added to the input mix for biomass conversion.

Resource	Annual Production (Kt)	Reference	Energy (GJ/t)	Ash (%db)	Methane production (m3/t)	Methane energy (MJ/m3)	Reference
Municipal Green Waste	3	(DPC, 2007)	21.1	53			(Tobiasen & Stein, 2002)
Piggery manure	167	(Wu & Bartle, 2008) (Estate, 2008)			22	23	
Poultry manure	58		10.7				
Sewage	140						

Resource	Grower Price (AU\$/t)	Delivered Price (AU\$/t)
Municipal Green Waste	0	0
Piggery manure	0	40
Poultry manure	0	40
Sewage	0	40

5.4 OVERVIEW OF WHEATBELT BIOMASS RESOURCES

An overview of the biomass resource potential in this region will be based on the information presented so far, interpreted in terms of potential electricity and Biofuel production. To make these interpretations a number of general assumptions are required relating to transport costs, energy and cost of replacing lost soil nutrients, electricity generation efficiency, and Biofuel conversion efficiency.

Transport and handling of biomass resources can be a significant cost when distances and areas involved are so large. A notional transport and handling cost will be established so that delivered price can be used for assessing biomass feedstocks.

5.4.1 TRANSPORT AND HANDLING

Cooperative Bulk Handling is a well-established business that manages collection and transport of most harvested grain in Western Australia. Using the CBH system makes sense for managing large amounts of seasonally produced biomass. Costs of handling are in the order of \$25-30/t. Transport from farm to CBH and then CBH to plant could amount to \$20/t. (William J Ryan & Michael L Poole, 2008)

Total cost of feedstock managed this way could be up to \$50/t (even assuming a price to farmers of just a few dollars per tonne of chaff, which would have to compete with using the chaff as animal feed by simply leaving on top of the straw wind rows in the field). According to Verve, oil mallee will be bought from the farmer (at \$15/t), harvested, and transported to a new Narrogin plant for around \$45/t. This gives a harvesting/transport/handling figure of \$30/t. (Conway, 2009)

For ease of calculation a compromise value of \$40/t will be applied for all biomass resources where there is no other price information is available, and the basic cost of the material is thought to be negligible. For use of process residues onsite a handling cost of \$15/t is included to cover additional costs, particularly storage of residues.

Other costs that may require consideration include the loss of biotic material when crop residues are removed from the farm. The loss of soil nutrient must be addressed.

5.4.2 COMPENSATION FOR LOST SOIL NUTRIENT

Figures for the replacement of soil nutrient lost in the removal of crop remnants are required to make a meaningful assessment of the viability of such feed stocks. The cost to the farmer for the nutrient lost in grain sold off the farm is accounted for in the grain price; the same should be true of crop residues removed. Energy cost of the practice should be considered also.

A simple analysis of these losses looks at the amount of nitrogen removed with residues, and the cost and energy content of fertilizer to replace this nitrogen. Nitrogen loss is by no means the only soil cost of residue removal, so a more profound analysis would be required when assessing a particular situation.

Nitrogen (N) content of crop residues is approximately 0.32%/wt. (McNeal et al., 1968; Tobiasen & Stein, 2002)

Based on Urea (46% N), at 2009 Australian prices, cost of N is AU\$1500/t. Therefore, cost to replace nitrogen lost is AU\$4.80/t of residue. (Pivot, 2005)

Production of a kilogram of N for inorganic fertilizer requires up to 68 MJ of energy input. Therefore energy required for every tonne of residue removed is 218 MJ (0.22 GJ). (McLaughlin, 2000)

5.4.3 ELECTRICITY AND BIOFUEL CONVERSION EFFICIENCIES

Bioenergy plants in the Wheatbelt would most likely be in the 5-10 MW range. According to the US Department of Energy, electricity generation in these plants can be as high as 40%, but is generally in the low twenties. (USDOE, 2005) It should also be remembered that some sites that already have an processing operation active will be looking to install cogeneration plants, using the heat in their process, and consequently achieving much higher efficiencies from the feedstock. A conversion efficiency of 20% will be assumed for this study.

Bioethanol is produced in first-generation processes from the fermentation of sugars and hydrolysed starches. Second-generation processes, which are in the process of commercialisation worldwide, the woody, cellulosic parts of plants are taken as the feedstock. Although yields from second-generation processes tend to be lower, the cost and quantity of feedstock available is very favourable.

Ethanol is the best studied of alcohol biofuels, and so is used as a means to compare biomass resources that may be used for any related process. Processes that are related to ethanol production include production of other alcohol fuels like methanol and butanol, and biopolymer production from starch and cellulose.

For the purposes of this study, the following approximate figures will be used for conversion rates.

- Cereal Grains 320 L/t
- Cereal Chaff fraction 170 L/t

- Cereal Straw fraction 70 L/t

(Kim & Dale, 2004; O'Connell, 2008; USDOE, 2009a)

Biodiesel is produced from conversion of biolipids (vegetable fats and oils). Again the comparison of resources by biodiesel yield is for convenience, remembering that other processes including bio-polyester and bio-lubricants rely on the same lipid content.

Biodiesel conversion from pure biolipids (extracted fats or oils i.e. canola oil and tallow) is assumed to be 97% by weight. So for every tonne of oil, 970 kg of biodiesel can be produced. Biodiesel has a specific gravity of 0.876 (t/m³), so volumetric yield is taken to be 1100 L/t. (Expo, 2008)

Given these conversion efficiencies, the relative size of the various resources identified can now be compared. The complete table of results can be found in Appendix 1.

5.5 SUMMARY OF RESOURCE SURVEY RESULTS

This summary presents some figures and comparisons to give some perspective on the quantity of resources that have been identified in this survey.

Electricity potential

Total electricity production from energy content of all available resources 7246 GWh/a

Total electricity production from energy content of available crop residues 6483 GWh/a

Total electricity use in Australia was 242500GWh and in WA was 14500GWh (6% of national consumption) in 2008. (ABARE, 2009b) The total residential electricity consumption in the Wheatbelt is 576 MWh/day, or 210 GWh annually.

Available resources, after all caveats discussed in this section, are enough to supply half of the state's electricity requirements on an ongoing basis. The crop and processing residues account for almost 90% of this energy.

Ethanol Potential

Ethanol production capacity from crop residues is 500 ML.

National market for ethanol using E10 blend (10% ethanol in unleaded petrol) is 2814 ML.

Potential ethanol production from crop residues represents 18% of the Australian market assuming an E10 mix.

Biodiesel Production

Biodiesel production capacity from tallow and used cooking oil in WA is 27.6 ML.

National B5 (5% mix with mineral diesel) biodiesel market is 882 ML.

The tallow resource could potentially supply 3.1% of the Australian B5 market.

If canola oil is available for biodiesel production, potential production is 304.6 ML (34.5% of the Australian B5 market).

5.6 RESOURCE ASSESSMENT CONCLUSIONS

Agricultural residues may represent low hanging fruit for the establishment of some bioenergy production in Wheatbelt WA. In the long term it is likely that some of this residue will be required for maintenance of soil quality, and will not be available to biomass industries. It seems wise to identify what is the fraction that is appropriate to use, and what is a suitable compensation for its use in terms of soil quality. This is a subject for which guidelines should be put in place sooner rather than later.

Woody crops have the potential to feed bioenergy, and then biorefineries, in a sustainable, long term way. The potential for woody crops to improve agricultural practices and benefit biodiversity is the subject of numerous reports but is beyond the scope of this one. A broad sense of the potential for these crops is given in Figure 14 (the four bars shown for each zone show the bioenergy potential calculated using four different methodologies).

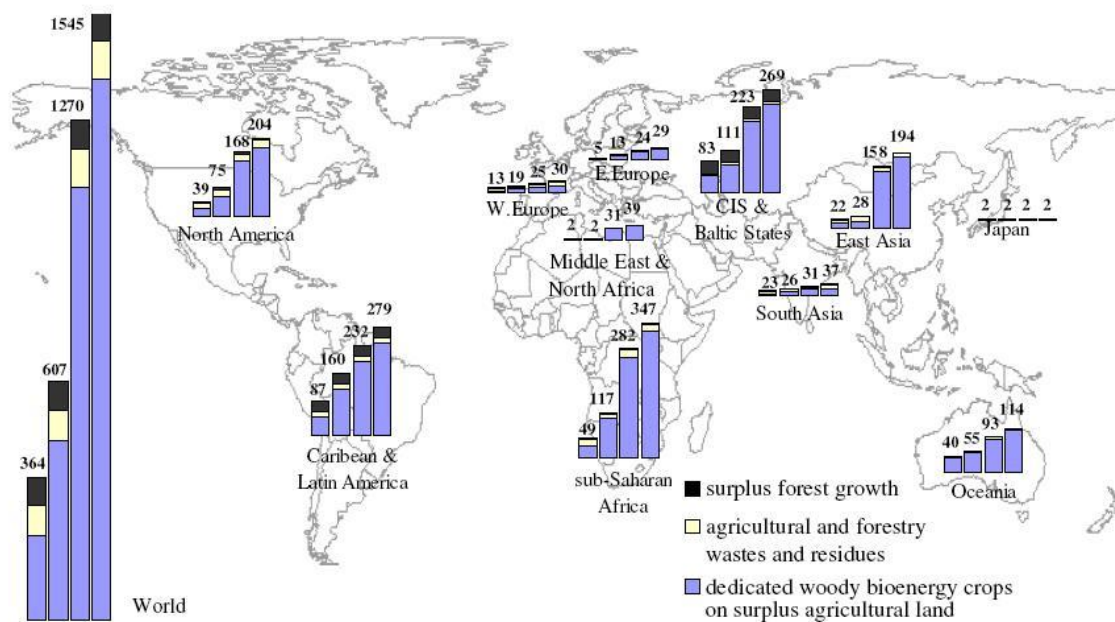


FIGURE 14: BIOENERGY PRODUCTION POTENTIAL (SMEETS & FAAIJ, 2007)

Woody crops will undoubtedly play an important role in the environmental and economic future of Wheatbelt, and it is important that the considerable amount of research work that has been done be supported continued striving for commercialisation of the crops. The externalities of projects based on woody crops as a feedstock should include water table management, consequent salinity mitigation, carbon fixing, erosion reduction, wind breaking, biodiversity improvements, alternative income generation for growers, and increased energy security for regions. This is an unusual business case, where the externalities are driving the desire to initiate projects, rather than the presence of ready profits.

The time lag in establishing woody crops could be anything up to 10 years, even if the wheels began rolling today, an alternate feedstock is required to get biorefineries established. Processing plants in the region are well placed to produce energy that can be used onsite, and that can allow for new and innovative processes to be included in their operations. Where these processors have combustible waste streams the idea is particularly viable.

Biorefineries based on crop residues have the potential to access vast quantities of feedstock. The cheap energy that could be produced from this feedstock would automatically encourage expansion and diversification of industries in the region, but there is also the possibility of using the feedstock to produce more interesting, and potentially valuable, products. The key to sustainable biorefineries lies in ensuring that feedstock is produced in a sustainable manner. The full lifecycle impact of biorefinery can have positive or negative impacts environmentally and socially.

Having energy and other resources on site will attract other businesses. The following chapter will examine the idea of biomass industry hubs, and the concept of the biorefinery.

6 INDUSTRIAL HUBS AND THE BIOREFINERY CONCEPT

A bio-refinery, in the most general sense, is a facility that takes biomass as an input and converts that biomass into one or more products. This study will discuss the concept of a biorefinery in the context of a biomass process industry hub. It is necessary to establish clear definitions of each concept, and to differentiate between them.

6.1 INDUSTRIAL HUBS

An industrial hub is a site where multiple industrial operations have co-located to improve capital efficiency by sharing infrastructure. Some general examples are:

- **Intermodal Transport Hub** (where different transport modes like road and rail intersect and a changeover is facilitated)
- **Technology Hubs** like the famous Silicon Valley, where numerous companies working in the same or related areas collocate to share resources. In the case of Silicon Valley, the presence of Berkeley and Stanford Universities nearby were the driving resources that kick-started the hub.

When a hub works well it creates a certain momentum. In the case of California's Silicon Valley, the integrated circuit (IC) manufacturers were soon joined by companies making equipment like the semi-conductor furnaces used for IC production, and then by companies making software to help with IC design. (Kenney & von Burg, 1999) These may be thought of as *supply chain synergies*.

An example of a well established industrial hub in Western Australia is the Kwinana Industrial Zone, in the southern coastal part of Perth. The first facility in the area was the oil refinery (now operated by BP) that was established in 1952. 2400 acres of land around the refinery was set aside for industrial usage and is now dense with industrial activity. Interactions between industries in the area began pragmatically, based on sharing of infrastructure (roads, power lines etc.) and utilization of one company's waste stream as an input to another process by another company in the area. The Kwinana Industries Council (KIC) now actively pursues these interactions (*synergies*) through various programs, including the Centre for Sustainable Resource Processing (CSRP) Kwinana Synergies Project. A report from the Kwinana Synergies Project identifies 47 existing synergies, along with 90 more potential synergies. Of the 47 existing synergies, 15 are categorized as *utility synergies*, meaning that, for example, fuel gas produced at the oil refinery is piped to the Kwinana Cogeneration Plant to fire the gas turbine. In that case the Kwinana Cogeneration plant then send steam and electricity back to be used at the oil refinery. There are 32 *byproduct synergies* including use of lime kiln dust from Cockburn Cement for chlorine removal in the pigment process at TiWest. (Beers, 2008) Some of these synergies are illustrated in Figure 15.

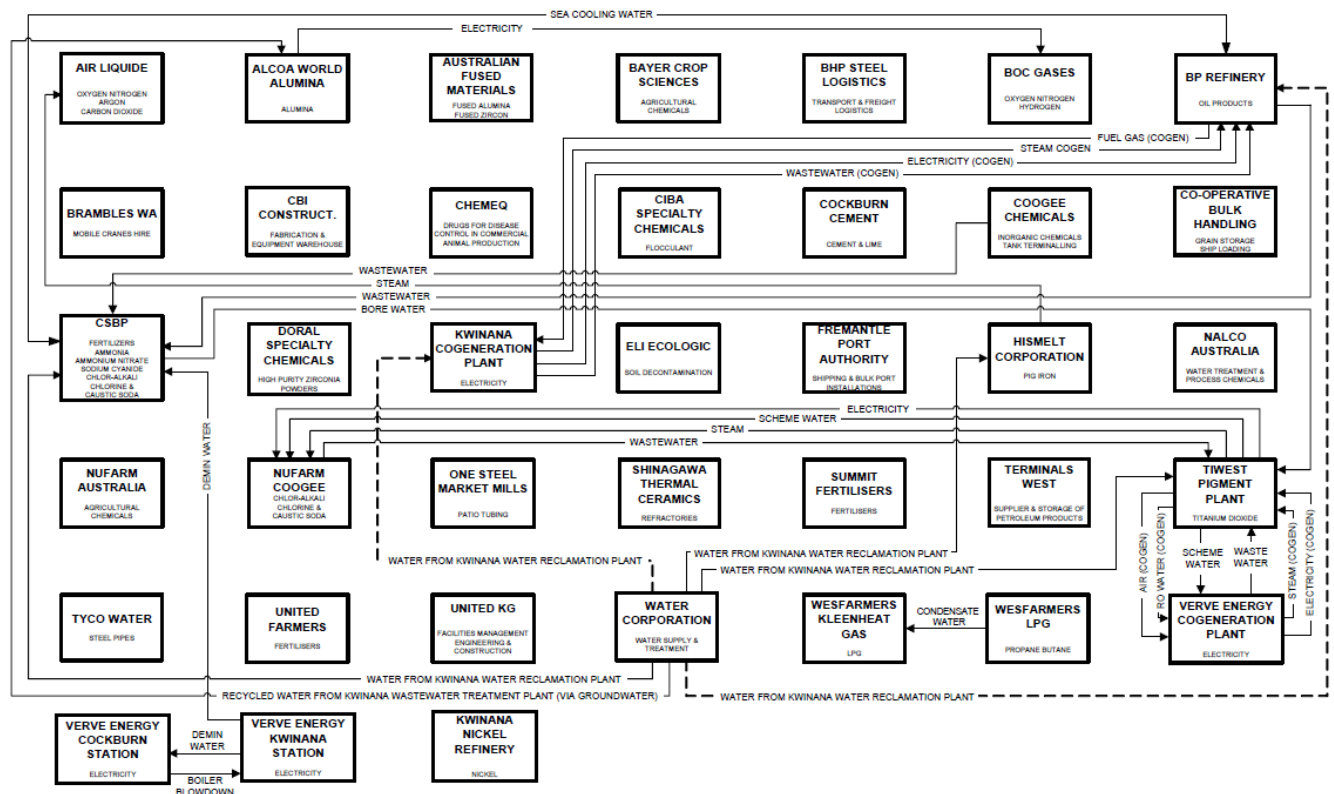


FIGURE 15: SOME EXAMPLES OF SYNERGY FLOWS IN THE KWINANA INDUSTRIAL AREA (BEERS, 2008)

So the strength of the hub idea is that it facilitates interactions, or synergies, between companies that collocate.

- **Supply chain synergies** (where a number of operators in the hub may need a common product type e.g. acetic acid, or electricity used by multiple operators in the area at a volume sufficient to merit a producer, or generator, setting up locally)
- **Utility synergies** (where common infrastructure reduces capital expenditure for individual companies e.g. car parks or handling facilities)
- **By-product synergies** (where a process output is not easily utilized by the processor and a neighbouring operator is able to use it as an input e.g. fly-ash from thermal power station smoke stack scrubbers may be used for concrete or brick manufacture)

A development of the use of by-product synergies is to plan a facility so that these synergies are designed in. The planned integration of 'by-products', which are better now thought of as 'co-products', may improve the economic viability of the facility. The facility may be based around a number of inputs, with a number of outputs, and a number of conversion pathways in between. This is the concept of the biorefinery.

6.2 BIOREFINERY CONCEPT

A biorefinery is, semantically, a refinery that uses a biomass feedstock. The additional meaning that is implicit in this study is that a biorefinery should not be a single purpose process that values only a single product. The biorefinery concept is an attempt to embody a new way of thinking about industrial design that has been developing over the last few

decades as awareness has grown about the scarcity of resources, the value of a healthy environment, and the damage that has occurred since the industrial revolution.

6.2.1 AVAILABLE DEFINITIONS

Biorefinery—According to the 2008 Farm Act (USA), the term means a facility (including equipment and processes) that converts renewable biomass into biofuels and biobased products, and may produce electricity. (USDA, 2009)

Biorefinery: A factory where biomass is processed into biofuels, biochemicals, biomaterials and other bioproducts. By-products are used to power the factory or are turned into other products. (Lakes, 2009)

Biorefinery: An industrial facility that takes biological material as its input, and transforms it into a variety of valuable chemicals, materials, fuels, or power. The biorefinery is a parallel concept to the petroleum refinery, which produce multiple fuels and products from petroleum. (BioCanada, 2009)

Biorefinery: A facility for the production of biofuels. (Green, 2009)

6.2.2 FOR THE PURPOSES OF THIS STUDY

- **Industrial hubs** “are characterised by the close geographic proximity of the industries, open communication, a diversity of enterprises, and large, continuous by-product streams from two or more major process industries, which can be utilised by neighbouring industries.” (Pyper, 2006)
- A **biomass industry hub** is a set of biomass conversion facilities, which are co-located, and which share infrastructure. Generally, a number of different operators will be involved.
- A **biorefinery** is a set of integrated biomass conversion processes connected by material flows. A biorefinery may produce energy for its own use and for export to other energy consumers.

6.3 BIOREFINERIES AND BIOMASS INDUSTRY HUBS

CONCLUSIONS

At the simplest level, a biorefinery is a facility in which biomass is converted into a useful product or products. The term has come to imply a facility which makes valued use of by-products (co-products), and which provides some, or all of its own energy needs.

7 BIOREFINERY CASE STUDY

The Integrated Wood Processing (IWP) plant in Narrogin, WA, is designed to take in woody biomass and produce electricity, heat, eucalyptus oil, and activated carbon. The plant ran briefly in 2006 and been pronounced a success by the stakeholders, including Verve Energy and the WA State Government, and will be examined briefly as an example of the biorefinery concept. A part of the original motivation for this project was to add a commercial driver to efforts to replant some areas of the Wheatbelt in order to combat dry-land salinity. (Verve, 2006)

Australia currently makes very little use of woody biomass (anything from twigs and leaves, to logs) for energy production, outside of the household fireplace. Australia currently produces less than 500GWh a year of electricity from the residues of forestry, sawmilling and other wood processing operations, such as pulp and paper manufacture. The Clean Energy Council estimates there is potential to boost that 6-fold by 2020 and 12-fold over the long term from a total resource of 8.8 million tonnes. (CEC, 2008)

7.1 IWP OVERVIEW

The idea of integrated tree processing is to maximise the value of woody biomass by using integrated processes that generate diverse products from the feed stock.

The plant was designed to Verve Energy's requirements by Enecon Pty Ltd, using some technology licensed by Enecon from CSIRO.

A feasibility study was completed in 1999. Funding was raised (mainly from the Australian Greenhouse Office, AusIndustry, and Western Power) during 2000, and the project was delivered in 2006.

Products of the integrated process were to be process steam (actually used within the plant), electricity (1MW continuously), activated charcoal (used in filtration and soil treatment), and eucalyptus oil (an aromatic oil with a large market and diverse uses).

7.2 PROCESS

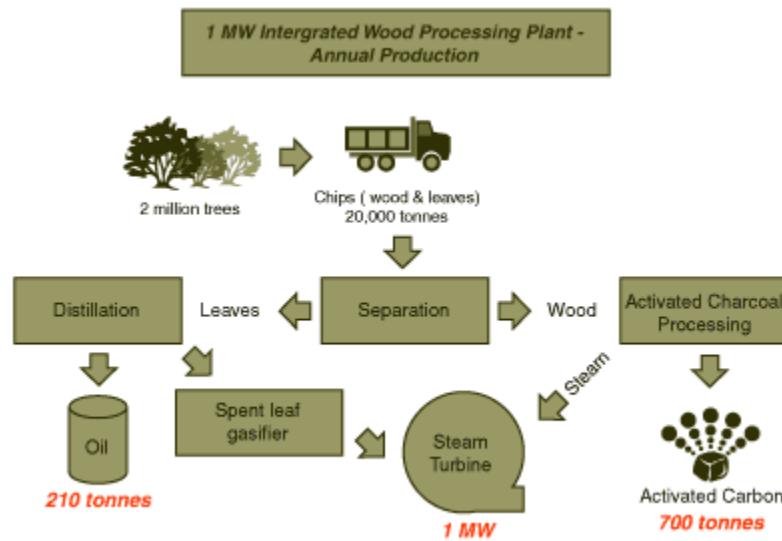


FIGURE 16: IWP FLOW DIAGRAM (OMA, 2008)

Figure 16 shows a schematic overview of the IWP plant at Narrogin. Several of the operation units shown in this diagram were to be proved by the pilot plant, particularly in the context of a continuous (as opposed to batch) operation.

- **Cultivation** of 2 million mallee eucalypts to specification was required to feed the plant. Growth rates, biomass densities, and effect on the planted area were all of interest
- **Harvesting** of the mallees is still a process being perfected. A dedicated mallee harvester is apparently being developed in Queensland. The W.A. state government gave a \$1.5 million grant to develop a harvester in June 2008. Other funding has come from Federal grants
- **Separation of leaves and wood** was a crucial operation because the leaves are used to extract eucalyptus oil, whilst the woody part is used to make activated charcoal
- **Gasification** of leaf matter, after oil extraction, created gases, which were burnt in an afterburner to fire a steam boiler
- **Activated Charcoal Processing** was performed using a new fluidised bed technology developed by CSIRO
- **Oil extraction** as a continuous process needed proving
- **Steam turbine** operation was an established technology

(OMA, 2008; Verve, 2006)

7.3 IWP REVIEW

State Government

In June 2006 Fran Logan, Energy Minister at the time, announced the success of the pilot plant and directed Verve to call for interest in developing commercial scale plants. (DOIR, 2006)

He said that since the trials began, the plant had scored several significant Australian achievements. These included:

- the first biomass gasifier to generate electricity into an electrical grid
- the first bioenergy generator to use a farm-grown energy tree crop
- the first production of activated carbon from an energy tree crop
- the first eucalyptus oil still to operate off process waste heat
- the first charcoaling plant to use a super clean fluidised bed

Verve Energy

“Verve Energy has successfully demonstrated the IWP technology through the demonstration plant at Narrogin. Now Verve Energy wants to take the next logical step and build the first commercial scale IWP plant, with a view to further development in the future.” (Verve, 2006)

National Association of Forest Industries submission to Dept Resources, Energy and Tourism, June 2009

The Narrogin project offers renewable electricity generation and the potential to commercialise charcoaling and carbon activation technology. The demonstration plant showed, inter alia, that:

- Renewable electricity can be produced for sale.
- The overall process technology can be scaled up from batch to continuous operation.
- The biomass delivery system can be developed.
- The proposed continuous harvesting system has benefits in terms of quality and cost.

(NAFI, 2009)

7.4 IWP CONCLUSIONS

The IWP plant in Narrogin is considered by stakeholders to be a successful demonstration of continuous operation mallee processing. Data from the operational run of plant is not publicly available, at this stage, but discussions with operators indicate that further work would have been required to make the plant a viable proposition longer term operation.

The most basic original drivers for the project were actually external to the commercial and technical aspects of the facility. The desire to find a commercial driver for tree planting in

the Wheatbelt to both address dry land salinity, and act as a carbon sink, were behind the inception of the project. (Verve, 2006) The designers were therefore driven to maximize the value of the feedstock, so as to be able to offer an incentive to growers, and hence they arrived at a design with the multiple conversion pathways that define a biorefinery. This is what makes the IWP such a potent example in the context of this study.

Verve is known to be considering a commercial scale expansion of the project. The proposals for the expanded project have changed from the original in that the commercial argument is being made solely on the viability of the plant as an electricity generator, rather than as an integrated process. (Conway, 2009; Verve, 2006)

Other potential sites for biorefineries to be developed in the Wheatbelt will be examined, including a site in Williams and one in Wagin. Existence of industrial processors, who have expressed interest in the bioenergy/biorefinery idea, makes these sites attractive.

8 POTENTIAL BIOMASS HUB SITES

Biomass processes can theoretically be located almost anywhere. As with any high-energy facility, safety from fire and air pollution for nearby people and activities is a design basic. Noise and visual pollution are also basic design considerations, remembering that the facility could potentially run 24 hours a day.

Another consideration is community resistance to biomass facilities. People fear toxic air pollution as well as smell from a biomass facility. Even if these fears prove unfounded, the same perception may affect future potential property buyers, with a negative effect on prices. It is reasonable to keep industrial facilities like biorefineries remote from residential areas, and established industrial sites make the most effective options.

8.1 WAGIN

Wagin is a small WA town of 2427 people (ABS, 2006) in the southern Wheatbelt (Great Southern Region) about 3 hours drive from Perth.

8.1.1 WAGIN SITE

Morton Seed and Grain Pty Ltd run an oat processing plant on Dumbleyung Road, just out of Wagin town site. There are 7 end products.

- Kiln dried groats (hulled oats)
- Kiln dried steel cut groats
- Steel cut groats
- Green groats
- Birdseed groats
- Feed oats
- Oat husk

The terms hull and husk are used interchangeably throughout the literature. The husk, or *hull*, of the oat is a woody shell that protects the seed (the *groat*) inside. Groats are any grain with the husk removed, leaving the softer seed part.

8.1.2 PROCESS OVERVIEW

During harvest the oat grains are separated from the chaff (the remainder of the head of the oat grass) in the harvester. Before the oats can be used the hull is generally removed. Hulling is a continuous process that accelerates the oats and throws them against a sprung surface. The impulse change on impact tends to cause the denser groat to break out of the hull. Empty husks are separated from the groats by blowers.

The groats then continue on to further processing.

8.1.3 GROATS

Groats are the food part of the oat plant; the seed. These are cut, dried, rolled and processed in various ways to produce human food and animal feed. These processes are the main activity of the current facility, which consumes electricity, gas and water for steam, as well as the oat feedstock.

8.1.4 HULL

The hull, after separation from the groat, is a process residue or waste. Morton had been disposing of this by spreading it on some open land near the Wagin airstrip. Disposal costs \$15/t. This practice has been an added cost to the processing, created a potential fire hazard (large amounts of dry material, which did in fact catch fire early in 2009), been a source of greenhouse gases during decomposition, and represented a wasted resource.

The potential to do something useful and cash positive with this processing waste stream was identified by Morton, and a biomass fired boiler was installed in early 2009. It is proposed that this initiative be developed into the beginnings of a biorefinery and biomass hub around the Morton Grains site in Wagin.

8.1.5 QUANTITIES

Morton Seed and Grains to assist with this study provided the following data:

- Standing costs are \$150000 /yr
- The facility employs 17 people
- Feedstock cost of oats \$150 /t
- Processing cost \$70 /hr
- Cleaning of feedstock 20 t/hr
- Dehulling 7 t/hr
- Husk produced by hulling 3-4 t/hr (total 22000 t/a)

8.1.6 PROPOSAL

The initial stage of the project proposal for the Morton site in Wagin was to install a boiler, fired by the oat husk residue, to produce process steam for use on site. Morton installed a continuous feed boiler in August 2009, and is in the process of completing commissioning. Teething problems have mainly been related to the feed stock fuel management part of the boiler, and particularly ash and slag build up. It is a moving grate type boiler with air injection by an electric fan arrangement. Once operational the boiler should be capable of satisfying the process steam requirements of the plant. This boiler constitutes a trial solution to the process residue issue, which they consider successful, and intend to expand.

It is proposed that a high pressure boiler, capable of producing 10MW_{TH} (thermal energy rate). This plant would utilize a substantial amount of the oat husk resource to produce both electricity and steam. Significant work has been undertaken to this end with Swedish company chosen to provide a 10MW_{TH} combustion boiler coupled to their patented steam

engines. The maximum electrical output of this facility is 2.5MWe (electricity) using 2 x 1MW and 1 x 0.5 MW steam engines.

The exit steam from the steam engines would have enough enthalpy to remain useful in the oats processing. It is expected that steam at 1-2 bar pressure, at 120°C would be available in large quantities.

The estimated capital cost for this complete system is approximately \$8 million.

With the installation of this system, Morton Seed and Grain would realise savings in gas and electricity costs in excess of \$700 000/yr. These savings will increase as electricity costs are set to increase by at least 60% by 2013. Further income would be through Renewable Energy Certificates as this resource is an agricultural residue.

To reduce the investment risk associated with this project Morton Seed and Grain has applied for a \$3 million grant under the Rural Food Processors Innovation and Productivity Program. The outcome of this application will be known by mid December 2009.

Excess electricity production could be exported to grid. Early inquiries indicate that the power line that connects the site to grid electricity is not capable of accepting more than 10 kW without being upgraded. The alternative is to use more electricity on site. Other processes could be added to the oat facility such as rolling and toasting the oats. Competitively priced electricity could attract numerous other processors, and in this way an industrial hub could begin to evolve.

8.1.7 WAGIN WATER WOES

Wagin, like most Wheatbelt towns, was established along the grain haulage railway. The railway was built along the flattest ground, which was coincidentally the lowest lying. Land clearing has lead to ground water rising, and becoming salty as it passes through layers of soil that have held ancient sea salt captive for millennia. This water is causing salinity problems all over the Wheatbelt, but also has direct effects on buildings in towns like Wagin. The shire has been pumping ground water out from under the town at the rate of 650KL/day into a saline dam lake over a ridge. This solution is highly unsustainable because it only temporarily displaces the water, it makes the lake more saline, and there is an energy cost in the pumping.

A desalination plant could make further use of the excess electricity and steam at the Morton Grains site. Reverse osmosis (RO) has been the technology of choice in desalination for some years now, but thermal methods have been evolving in the background, and represent a viable choice. Of particular interest may be the combination of RO, which has high electricity demand, and excess thermal energy from onsite cogeneration being used to process the post RO effluent. The effluent from desalination processes is even more of a problem in-land than it is for coastal desalination plants. Advanced discharge treatments hold the promise of reducing liquid discharge to zero, and of resolving the effluent into separate, useful components. (Arakel & Mickley, 2009)

8.1.8 NOTIONAL DESIGN

It is proposed that excess electricity be exported to the grid in the short term, if a cost effective means to do so is available. May require government investment or additional grants. Additional use of heat, power, and brackish ground water could be made by aquaculture (fish farming), according to a interested group from a WA agricultural college. Figure 17 shows a schematic interpretation of some of the ideas that would fit the situation at the Wagin site.

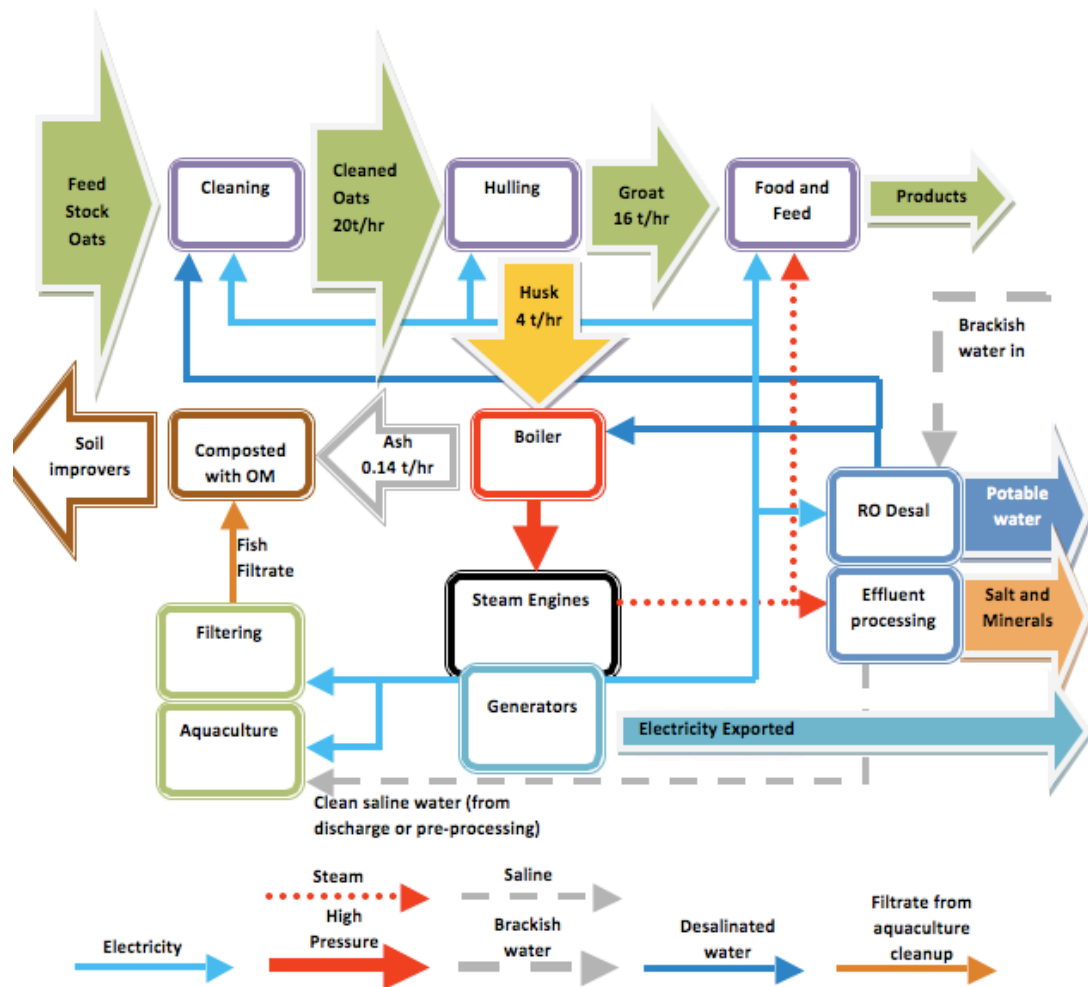


FIGURE 17: SCHEMATIC DESCRIPTION OF A PROPOSED INTEGRATED PROCESS AT MORTON GRAINS IN WAGIN

8.1.9 WAGIN CONCLUSIONS

More work and access to commercial information is required to get the design to a point where the economics can be usefully assessed, but given the availability onsite of a feedstock which is currently an input cost to the processor (cost of disposal), it is very likely that a viable biorefinery design can be arrived at.

The progress of currently lodged grant applications will decide how ambitious plans at Wagin can be, and how quickly they will proceed.

8.2 WILLIAMS

Williams is a small Wheatbelt town, population 400 (with just over 1000 people in the shire).

Macco Feeds is an animal feed producer located near the town. The processing plant blends quantities of straw, meal and grains into pellets, with compositions tailored to the requirements of different animals. This processing facility is located on a farm that already grows in excess of 500 T of Canola and is in close proximity to other farms that grow similar quantities. Macco feeds purchases approximately 2000 Tonnes/yr of canola meal for pellet make-up. Furthermore, they operate a transport company that uses in excess of 1.3 million L of diesel per year. The site has existing diesel refuelling equipment, grain storage capabilities and transport infrastructure. Furthermore, Macco Feeds has strong contacts and existing relationships with agricultural producers and other related industries

The main current activity at Macco is animal feed pellet production using grains:

- Lupins
- Oats
- Barley
- Wheat

And other crop inputs:

- Canola meal
- Malt combings
- Oat husk
- Barley husk
- Straw
- Hay

8.2.1 PROPOSAL

Macco Feeds in Williams presents an exciting opportunity for integration of diverse biomass conversion processes. The facility is already accustomed to dealing with a wide range of feedstocks and variable volumes of material depending on prices and seasons.

The ideas that have already been discussed with the operator include biodiesel production, pelletisation of woody biomass, and production of soil conditioners. They are also in the process of installing a boiler to be fuelled with process residues, municipal green waste, and various other feedstocks where they can be sourced.

By installing a crushing mill onsite, Macco can produce the canola meal that they are already using in their stock feed pellets, and have a supply of canola oil for use in biodiesel production. Being able to tune the amount of oil left in the meal versus the amount of oil extracted is crucial handle for the economics of biodiesel production from canola

feedstock, because the oil content determines the value of the meal. (William J Ryan & Michael L Poole, 2008)

The mill and production plant would utilise steam, electricity, storage, and transport facilities available on-site. Canola meal could be used directly in the process and canola seed could be bought at the farm gate price with very low transport costs from the surrounding farms. A large portion (up to 50%) of the biodiesel could be used in the trucks operating out of the newly created hub, and glycerol could be used as a boiler feed in a proposed biomass cogeneration system. Combustion is the most cost effective use of glycerol under current market conditions, although there may be scope for purifying and selling the biodiesel by-product in the future.

8.2.1.1 PELLETISATION

The Macco Feeds facility is already engaged in production of pelletised stock feed from a variety of feedstocks. Although different machinery may be required to produce pellets from biomass, the general operation is substantially the same. Skills and handling equipment should apply readily to the new product.

Torre-faction may also be employed to increase the energy density of the pellets. Torre-faction involves heating the material to around 200°C (where pyrolysis begins) to reduce moisture content and to activate the pyrolysis oils. The oils have a binding effect, giving the pellet better structure. The result is a pellet that resembles coal (brown to dark brown in colour, hydrophobic), and has an improved energy density of 15-18.5 GJ/m³. (Bergman & Kiel, 2005)

Feasibility

Pelletisation could proceed in its own right, without any other biomass operations being co-located. The feasibility is assessed according to local and market information.

- Market for pellets produced at Williams
- Technologies available to produce them
- Feed stock resource available
- The plant can now be sized, capital costs estimated, and a value assessment made for the project

The market for fuel pellets is currently limited to the export market. Prices in Europe are linked to the price of coal because so much the pellet market goes to co-firing. Being an export market, prices are liable to fluctuate with limited warning. The price paid for biomass pellets in Europe (the main consumer so far) has been in the range £120/t - £360/t over the last few years. Transport from Australia must be considered for this market. Price for export pellets might be around AU\$50-100 /t.

Assuming that co-firing of biomass pellets could achieve the same levels as are seen in Europe, a local market can be estimated. Studies suggest that co-firing up to 20% pellets should not be problematic for a coal fired thermal power station. (Grassi & Senechal, 2008)

The Amager Power Station in Copenhagen, Denmark, is reportedly co-firing at this level. (Christiansen, 2009)

Of approximately 5.2GW generation capacity in WA, approximately 2.2GW are coal fired, or 42.3%. The average load is actually around 1.64GW over the year, so coal fired output is, conservatively, around 0.7GW continuously over the year (OOE, 2008). WA black coal has an energy content of 19.7GJ/t (ABARE, 2009b) and produces electricity with a thermal efficiency of 35-36% (Diesendorf, 2005). This equates to approximately 3.22Mt/yr WA black coal consumed for electricity generation. If 20% of this energy were to be met by biomass pellets, 0.64Mt/y would be required, assuming a similar energy content to coal. The Plantation Energy facility at Albany is producing 0.25Mt for export under a three-year contract. It is likely that any local biomass demand will be met from new facilities.

8.2.1.2 BIODIESEL PRODUCTION

Biodiesel production from the transesterification of Canola oil is a well-established biomass conversion process. The process begins with canola seed, which is pressed for oil, leaving canola meal, which is already used on site at Macco Feeds to produce stock feed. The oil is processed with methanol, in the presence of a catalyst that is not consumed. The methanol is mostly recovered and recycled, leaving biodiesel and glycerol as outputs.

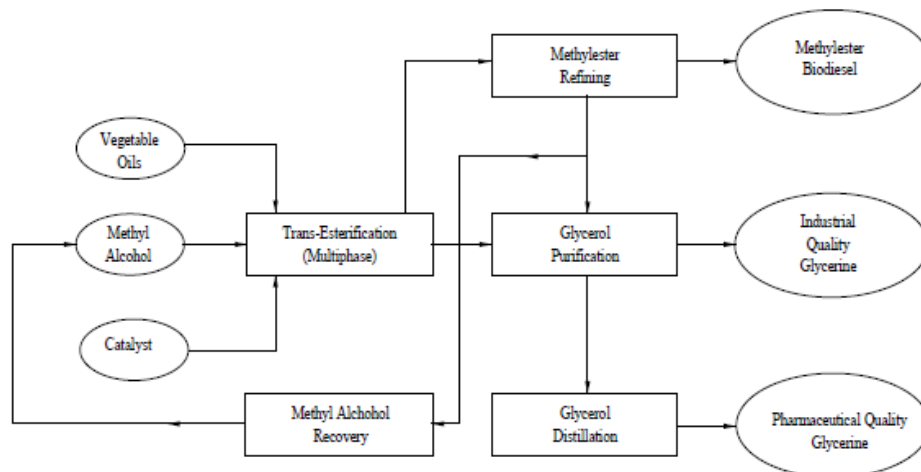


FIGURE 18: ESTERIFICATION PROCESS FLOWS FOR BIODIESEL (MCKENDRY, 2002)

The biodiesel can be expected to be produced for around \$1.30 /litre, with production costs being most sensitive to feedstock price. (William J Ryan & Michael L Poole, 2008)

Site-specific data is used to determine the actual selling price of diesel, the actual cost of canola and the realisable value of glycerol and canola meal. This analysis is then superimposed on commodity trends to conduct sensitivity analysis and determine the long-term viability of the plant.

Feasibility

This section is based on the work of de Boer, Taylor, and Bahri. (Boer, Taylor, & Bahri, 2009)

The proposed production system is based on a Bluediesel PTY LTD 2 million L/yr continuous production plant. This plant includes a pre-treatment module to handle tallow and a methanol recovery unit. Bluediesel PTY LTD estimates a cost of \$630,000 (installed) for this plant. The crushing plant consists of five 5 tonne/day oil presses and a degumming machine. Duff, (2006) estimates these machines to cost \$55,000, using this figure as a guideline a conservative estimate has been set at \$100,000 installed. The key inputs to this model are the value of the biodiesel, glycerol, meal and the cost of the canola seed. The variability of these key inputs is evaluated to determine a reasonable range for sensitivity analysis and conservative estimates are chosen for the base case. The sensitivity of viability of biodiesel production will be assessed against mineral diesel prices between \$0.90/L and \$1.40/L.

Like the diesel price, the canola seed price varies substantially being dependent on world commodity markets and local growing conditions. The canola seed price delivered to Melbourne has varied between \$313 and \$746 per tonne between January 2004 and September 2009, the average during this time was \$480/T (ABARE, 2009a). The farm gate price, however, can be up to \$60 less than the port price in Western Australia (William J. Ryan & Michael L. Poole, 2008). Due to the nature of the plant location and scale it is assumed that Macco Feeds can purchase canola seed at values very close to the farm gate price. With this in mind, the base case estimate is \$420/Tonne, while the range for the sensitivity analysis is \$380-580/T.

Most commercial biodiesel processes achieve a mass yield of 100% in the conversion of oil to biodiesel; this is also true for the Bluediesel process. The oil extraction is assumed to be 34% (Duff, 2006; William J. Ryan & Michael L. Poole, 2008). Using these efficiencies and a biodiesel density of 0.86kg/L at 25°C (Tate, Watts, Allen, & Wilkie, 2006), the plant requires approximately 5040 tonnes of canola seed a year. Canola is harvested in late November/early December, consequently this quantity of seed needs to be stored, the estimated cost of this storage is about \$400,000 (Beresford, 2009). This brings the total capital cost to \$1,130,000.

The meal has been assigned a value on the basis of the lupin price, as lupin can be used as a replacement in the production of animal feed. The average value of lupins between January 2004 and September 2009 was \$220/T. Beresford (2009) suggested that the actual lupin price at the mill is a further \$20/tonne above this average price, consequently a value of \$240 has been used in the base case. In the sensitivity analysis the meal price was varied \$60 either side of the base case (\$180/T - \$300/T).

Crude glycerol has a low value, with many small-scale producers having to find a way to dispose of this by-product. By locating in the regional industry hub the glycerol can be combined with agricultural residues in a proposed biomass cogeneration system to produce electricity and steam. For the base case shown in Table 12 there is sufficient energy in the glycerol to produce more than half of the electricity required and all the

steam requirements for the biodiesel and crushing plants. If the cost of steam and part of the electricity is assumed to be negated by the use of glycerol in the boiler, the glycerol has a value in excess of \$200/tonne.

The base case analysis in Table 12 includes the revenue from sales, the operating expenses, non-operating expenses and the profit before and after tax. The analysis has been setup as if the biodiesel and crushing plant were a separate financial entity to the existing feed producer. This allows easy comparison with existing case studies in the literature. It is more likely, however, that the feed producer would operate the biodiesel plant and thus purchase the canola seed and realise savings in diesel purchases (offset by biodiesel produced), boiler feed (offset by glycerol by-product) and meal purchases (meal produced).

TABLE 12: BASE CASE FOR ECONOMIC ANALYSIS

Category	Annual	Per/Litre	%
Revenue			
<i>Biodiesel Sales</i>	\$2,048,000	\$1.024	71.0%
<i>Glycerine Sales</i>	\$37,886	\$0.019	1.3%
<i>Canola meal</i>	\$798,056	\$0.399	27.7%
Total Revenue	\$2,883,942	\$1.442	100.0
Operating Expenses			
<i>Canola Seed</i>	\$2,116,059	\$1.058	79.5%
<i>Methanol</i>	\$113,058	\$0.057	4.2%
<i>Sodium Methylate</i>	\$20,556	\$0.010	0.8%
<i>Purification Resin</i>	\$32,625	\$0.016	1.2%
<i>Repair & maintenance @ 3% of CapEx</i>	\$33,900	\$0.017	1.3%
<i>Labour</i>	\$83,380	\$0.042	3.1%
<i>Electricity</i>	\$38,452	\$0.019	1.4%
<i>Gas (Steam Generation)</i>	\$16,188	\$0.008	0.9%
<i>Insurance</i>	\$25,000	\$0.013	0.6%
<i>Testing</i>	\$20,000	\$0.010	0.8%
<i>Misc Operational</i>	\$20,000	\$0.010	0.8%
Total	\$2,519,217	\$1.260	94.6%
Non-Operating Expenses			
<i>Depreciation @ 10% Capex</i>	\$113,000	\$0.056	4.2%
<i>Interest on Working Capital @ 7% p/a</i>	\$29,391	\$0.015	1.10%

Total	\$142,391	\$0.071	5.4%
Total Expenses	\$2,661,608	\$1.331	100%
Operating Expenses			
Operating Profit (Before Tax)	\$157,343	\$0.079	
<i>Corporate Tax at 30%</i>	<i>\$47,203</i>	<i>\$0.024</i>	
Operating Profit (After Tax)	\$110,140	\$0.055	
After Tax Rate of Return		10%	

The values for biodiesel, canola meal and glycerol sales as well as the canola seed cost are based on an output of 2,000,000L of biodiesel per year at the base-case prices discussed previously. In regards to the other variables, the long term methanol price was estimated to be \$600 based on historical data from Methanex (2009) and transport/handling costs from Coogee Chemicals. The sodium methylate price was set at \$2000/tonne and the purification resin at \$21,750/tonne with respective consumption rates of 6kg/tonne and 0.75kg/tonne of biodiesel produced (Bluediesel, 2009). on the basis of conservative industry estimates. Repair and maintenance costs were estimated at 3% of the capital cost, while the Labour costs included one full time employee and technical (Bluediesel, 2009). Electricity and gas costs were estimated at \$0.12/kWh and \$0.025/MJ with plant data used to determine consumption. Insurance, testing and miscellaneous operational costs were set at the fixed values as indicated in Table 12.

The cost of capital is shown as non-operating expenses with depreciation at 10% of the fixed capital cost and interest paid on the working capital at 7%, the working capital is taken as 2 months of operating costs (\$419 870).

8.2.1.3 PRODUCTION OF SOIL STABILISERS AND IMPROVERS

Soil stabilisers are a range of products designed to reduce soil erosion. Environmental soil stabilisers would be expected to maintain, or even improve, the quality of soils and their nutrient content.

Stopping erosion can be achieved in numerous ways. Covering the ground, either with plastic sheeting, or with a ground cover plant, is not compatible with cropping (even if it were economically viable). Ploughing remnant straw back into the ground after harvesting effectively allows access to the upper soil layer for microorganisms that can improve both the crop producing value of the soil and its erosion resistance. But this ploughing also has the effect of releasing large amounts CO₂, and is being discouraged in other countries.

Biochar nitrogen content is approximately 5% (Özçimen & lu, 2003), 11% that of Urea (46% N). Urea price varies greatly, but is expected to settle at around \$700/t over the next year. (Pivot, 2005) On this basis a fertilizer value of \$77/t can be placed on biochar. Of course there are likely to be other benefits from the other trace elements in biochar.

Another possible utilization of biochar is in compensation to growers for loss of nutrients when biomass is removed from their land. Crop residues have 0.32%/wt nitrogen content. (McNeal et al., 1968; Tobiasen & Stein, 2002), so for every tonne of crop residue removed, 64kg of biochar would be returned to the grower.

A final valuation would need more knowledge of the particular feedstock. It would be of high importance to the sale of biochar that it could be produced with consistent characteristics.

8.2.1.4 NOTIONAL DESIGN FOR MACCO FEEDS

A notional design for the proposal at Williams is shown in Figure 19. The first stage in the biorefinery involves increasing the amount of storage available to cope with seasonal fluctuations and provide a constant feed stock. Next a cogen unit will be installed to produce steam and power on site. Once this is established, the current stock feed pelletising operation will be extended to produce biomass fuel pellets. A biodiesel plant will be the final part of the foundations for the biorefinery.

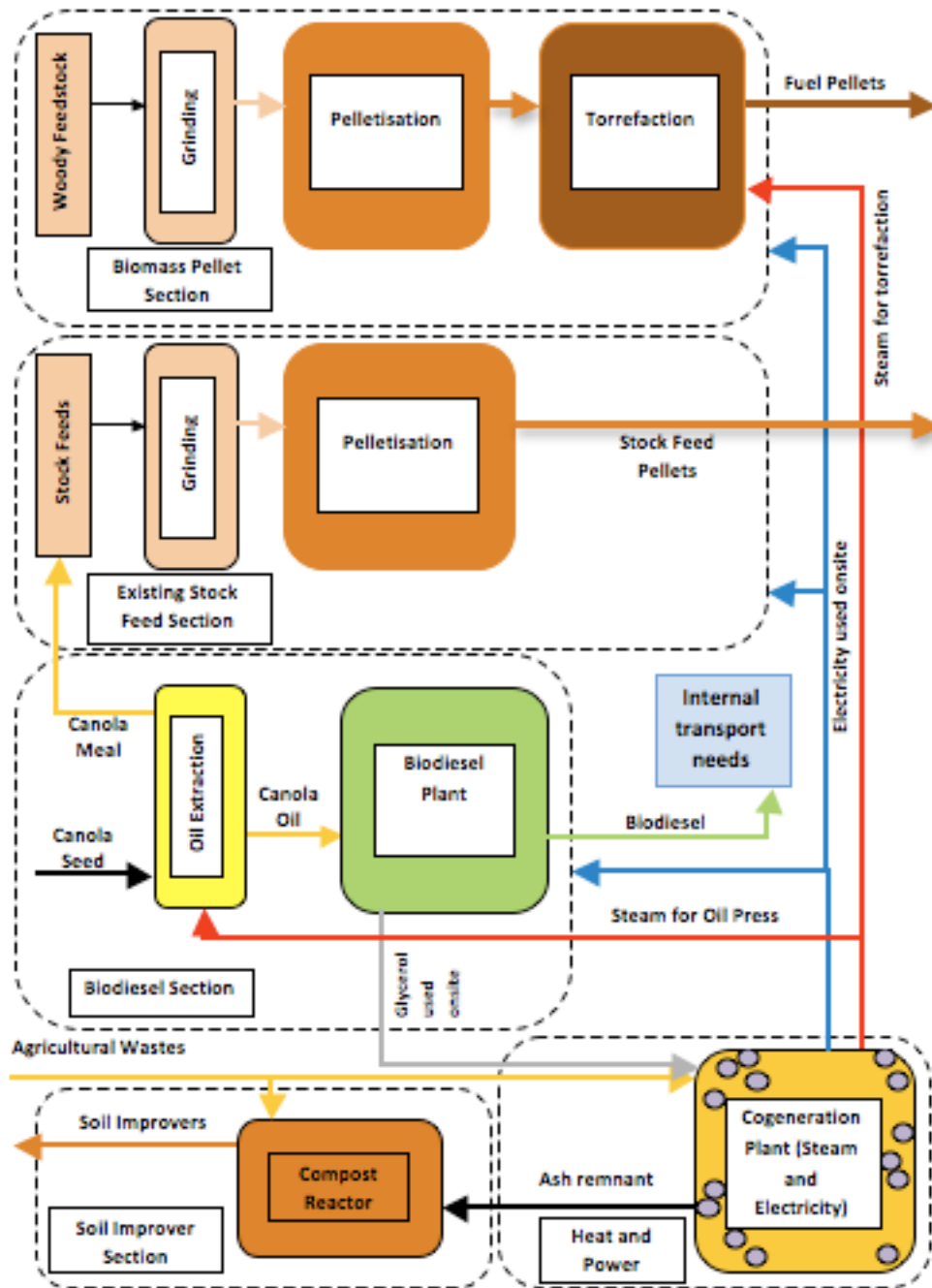


FIGURE 19: SCHEMATIC DESCRIPTION FOR MACCO FEEDS PROPOSAL AT WILLIAMS

There are numerous synergies at play in this design.

- Waste streams from stock feed operations can fuel the cogen unit
- The heat and power output of the cogen unit are used in other processes onsite
- The extension of the pellet operation into fuel pellet production will involve many helpful overlaps such as operator skills, handling machinery, storage facilities, and distribution systems
- The fuel pellets can be used onsite in the cogen unit, if the external market is not favourable at any time

- The canola meal output of a canola seed press would feed straight into the feed pellet operation
- The glycerol co-product of biodiesel production may eventually find high value markets that merit its purification, but until then it can be simply burnt in the cogen unit or used in the fuel pellets
- Biodiesel production will be substantially used on site (50% or more), reducing the vulnerability of the entire operation to diesel price fluctuations

With this set of units in place, the facility becomes somewhat self-sustaining; allowing the operators to focus on the introduction of more highly refined processes, such as starch based plastic production, cellulosic butanol production, and raw materials for composite boards (adhesives and fibre).

8.3 POTENTIAL BIOREFINERY SITES CONCLUSIONS

There are always costs and benefits to being the first. While mistakes and learning curves will be many, there will also be considerable support and interest from people and institutions that are interested in seeing the biorefinery idea succeed in Wheatbelt WA.

Price fluctuations in feedstocks, particularly canola, make economic assessment of these ideas somewhat fraught. On the flipside, having cogeneration and biofuel production onsite provides increased energy and fuel independence that will be a great strength in uncertain times.

When future operating conditions are more under the control of the operator there is more inclination to trial and experiment with new ideas. The Wheatbelt needs leadership from within, and processors like Macco Feeds and Morton Seed and Grains are well placed to provide this leadership in the areas of biorefining and energy production.

9 POTENTIAL UNIVERSITY INVOLVEMENT

There has been interest in possible Murdoch University involvement in a Wheatbelt biorefinery project from the operators at Williams and Wagin, as well as the shire of Wagin, and the Wheatbelt Development Commission. The university has considerable expertise to offer in development of a biorefinery, as well as much to gain from new avenues to commercialise research streams.

Murdoch currently has eight research institutes, the directors of which were contacted as part of the literature review period of this study to advise on viable directions for the biorefinery concept that was being developed, and to discuss eventual involvement of the institutes in a biorefinery facility.

Contacts with the institutes, as well as with various centres of excellence, and research projects are summarised:

Centre for Research into Energy for Sustainable Transport (CREST)

Bio-fuels, sustainable energy

Prof David Harries (Director)

Dr Harries is currently particularly focused on biofuels, with a new grant having been awarded to the CREST to look into small to medium scale biodiesel production. Biobutanol was discussed, including the fact that the BP/DuPont partnership to develop the fuel could turn the entire sector in that direction. Biobutanol from crop residues would make an excellent topic for R&D.

Institute for Resource Technology

Improving resource value and sustainability

Prof Doepel (Director)

The Australian National Centre of Excellence in Desalination (NCED) and Desal

Water processing

Prof Doepel (Director)

Although some discussion around resource sustainability has ensued, most contact with Prof Doepel has centred on desalination, since he became the director of the new National Centre of Excellence in Desalination. There is considerable interest in the 'energy-water nexus', which is the idea that the energy hungry nature of most desalination should be married to a renewable energy supply. This concept lends itself well to the combined roll out of desalination and bioenergy production in regional areas, particularly the Wheatbelt. The development of a package that

could combine energy and water in a relatively low maintenance way would be an excellent project, possibly shared between process engineering and the centre.

Institute for Crop and Plant Sciences

Improved crop varieties

Assoc. Prof John Howieson (Director)

To date, no reply was received from this centre. There is clearly potential in the medium to long-term development of crops that both address salinity issues and provide a biorefinery feedstock in the Wheatbelt.

Environmental Biotechnology Cooperative Research Centre (EBCRC)

Bio-films, bioremediation

Dr Ralf Cord-Ruwisch

No reply from this research institute. There will be opportunities for developing bioremediation techniques as part of a biorefinery.

Environmental Technology Centre (ETC/UNEP IETC)

Waste management processes

Dr Jaya Nair (Director)

Bio-digesters and composting are current ETC activities that could be a part of a biorefinery. There is also strong interest in establishing pyrolysis and gasification installations to study the potential of these advanced combustion techniques.

Institute for Sustainability and Technology Policy (ISTP)

Sustainable development and community issues

Dr Brad Pettitt (Dean of School)

A possible ISTP project in tandem with biorefinery was discussed. The likely approach would be to examine the issues around community engagement, and long-term regulation and assessment of the effect of a biorefinery in a given community.

Prof Goen Ho, Dr Ralf Cord-Ruwisch and PhD candidate Ka Yu Cheng

Microbial Fuel Cell

<http://www.research.murdoch.edu.au/ilo/docs/MicrobialFuelCellCollaboration.pdf>

Some discussion has occurred, particularly with Prof Ho, who is involved in a solar still project. No significant progress has been made on incorporating the fuel cell into a biorefinery design, and this seems an excellent opportunity for further work.

Western Australian State Agricultural Biotechnology Centre (SABC)

Agriculture research

Prof. Michael Jones (Director)

To date no reply was received from this centre. There would be interest in the development of feedstocks to suit a biorefinery.

10 ROADMAP FOR PROGRESSING BIOREFINERY PROJECTS

1. Establish arguments for bioenergy in Australia

- Address pros and cons, and get the public on board
- Assemble guidelines for development of bioenergy projects

2. Identify regional hub sites that are 'bioenergy ready'

- Resource availability
- Presence of suitable infrastructure (transport links, electricity, gas, water)
- Presence of amenable industrial players

3. Assess biomass resources available at the sites

- Quantities and trends
- Current uses, value and trends
- Energy value and basic chemistry of biomass
- Opportunities for new crops – openness of region to new activities

4. Assess possible products and processes suited to the resource types

- Review of by-products of the various energy conversion processes (combustion, digestion, gasification, pyrolysis etc.)
- Note any potential for other products (such as bio-degradable polymers etc.) from raw biomass, or secondary products
- Perform mass and energy balances for processes
- Examine economics and externalities of each technology

5. Develop notional design for hub

- Identify possible synergies and linkages available within the design
- Existing industries should combine in a viable way
- Compatible industries should be allowed for
- Open architecture as much as possible

6. Identify opportunities for additional innovative processes that may be viable within the hub

- Worldwide interest in biomass conversion has led to the development of a host of 'co-products' such as bio-plastics, bio-solvents etc.
- Any petrochemical product is a potential biomass co-product

7. Map opportunities against Murdoch activities

- Consultancy on implementation of everything from cogeneration to community impacts will be intrinsic to a successful biomass project
- An industrial hub may provide an excellent opportunity for a Murdoch facility aimed at commercialisation of processes that have synergies with established biomass conversion technologies

8. Develop a Murdoch facility that could sit in the hub, allowing smoother pathways for commercialisation of new processes.

- Interest in developing conversion technologies like digestion, gasification, and pyrolysis are all of interest to Murdoch research institutes like the ETC
- Distributed electricity, cogeneration, and RAPS systems are mainstays of Murdoch expertise at institutes like RISE
- Alternative fuels and transport issues are pursued by CREST

9. Use the hub/refinery as a platform for addressing broader issues (potentially accessing funds put aside for these issues)

- Water issues are endemic in the Wheatbelt (and worldwide) and set to worsen. Murdoch is a leader in desalination technology, hosting the NCED
- Salinity is a massive issue in the Wheatbelt. Numerous researchers at Murdoch are looking at this issue in different ways. New crops (such as the oil mallees already being trialled) may be viable if new conversion processes are available
- Economic sustainability is a looming problem for the region

At the kinds of sites examined in the Potential Sites section of this study (chapter 8), the project will have the following pattern:

1. Assess available biomass resources
2. Install a boiler to produce process steam
3. Add electricity generation to the boiler system by using the steam in an engine or turbine

4. Look for expansion in the current process and investigate new processes to take advantage of the steam and power onsite
5. Co-locate related processes, and or producers onsite (such as biofuel production)
6. Develop transport hub to improve life cycle efficiency of all processes
7. Identify process synergies at every stage of development of the site to maximise resource efficiency
8. Look to incorporate innovative processes, acknowledging that some may be winners and some losers. The identification of a successful new process will likely compensate for others
9. Talk to other people about successes and failures – shared knowledge has a multiplier effect
10. Monitor local effects of the project in terms of local attitudes other social aspects

CONCLUSIONS

Summation of issues identified

This study has identified a point of intersection between the needs of the Wheatbelt region of WA, and the desire of government and industry to expand biomass conversion operations, and biorefineries, across Australia.

Much has been written about the problems in Wheatbelt WA. Reports going back to the 1960s (that have been reviewed for this study) show that concern over the Wheatbelt dry land salinity issue has been around for a long time. While numerous technical solutions have been trialled, the only long-term solution on which there has been an enduring consensus is revegetation of a significant proportion of the region. The dimensions of both the problems and the solutions are such that no single action (such as a huge scale, government funded land purchase and tree planting operation) is likely to be on a large enough scale to make a difference. A driver is required to make a certain level of forest cover a standard part of agriculture in the region. Many drivers exist, such as grower's interest in the sustainability of the region, but the prime mover tends to be economic.

It has been shown that there is a global interest in biomass industries, and that Australia is lagging in development of this sector. Policy and strategy at all levels of government point to an increase in biorefining, and particularly in bioenergy production. Australia's electricity production from biomass is recommended to increase four-fold over the next decade. Feedstock tends to be the major factor in the viability of biorefinery projects, and so identifying potential feedstock sources is a major part of any biorefinery project proposal. Global rejection of the use of food crops to make biofuels, and the need to encourage a sustainable approach to agriculture combine to focus the search for viable biorefinery feedstocks in three places: wastes, fuel crops on non-food producing land, and agricultural residues.

Biorefineries that take woody biomass as a feedstock have great potential to provide the economic engine for the work that needs to be done in the Wheatbelt. Unfortunately, as examined in chapter 7, the most significant trial of this idea so far has stalled. Although the Integrated Wood Processing Plant at Narrogin remains a model for the medium term development of biorefining in the Wheatbelt, it is likely to be a decade before a full-scale version could come on line because of lead-time on producing the feedstock.

Use of agricultural residues and wastes has less direct effect on the problems identified in the Wheatbelt, but the increase in effective use of resources will have many indirect benefits.

- Reduced landfill
- Reduced greenhouse emissions from decomposing organic material
- New income streams for growers, improving economic security of the region
- Improved energy security through regional production of electricity, heat, and transport fuels

- The development of biomass industry hubs around biorefinery sites will allow for innovative processes to establish with much reduced capital expenditure, and with an existing context for their operations (transport, buyers, raw inputs etc.)
- Biomass Industry Hubs will already be in place once woody biomass feedstock is available on a large scale, so growers will feel more secure that the fuel crops they establish will find a reliable market once they are harvest ready in five or six years
- The *green jobs* potential of biorefineries will improve the opportunities for interesting work in the region
- Capacity building in the population of the Wheatbelt will improve viability of future biomass industry expansion

The general emphasis on diversification that the best examples of biorefineries bring to industry and agriculture will be a driver for more imaginative approaches to problem solving in the region.

Methods

The approach of this study has been to establish the macro drivers for biorefinery projects in Wheatbelt WA, and then to look at the factors that might provide the micro drivers to engage people in making the potential projects a reality.

The macro drivers were identified through the policy environment that the projects would face by examining policy statements and strategic documents, and filtering these according to the particular context of the Wheatbelt region and its needs.

Micro drivers were identified by review of publications on the region and by meeting with stakeholders in the region. Given more time and resources, it is this second part of the process that should be expanded to improve the value of this report to those considering new projects in the region.

A separate stream of inquiry has been pursued on potential involvement of Murdoch University in biorefining in the region. Potential stakeholders at Murdoch have had input into the technologies that have been examined in this study.

The technical aspect of the study has been concerned with matching resources available in the Wheatbelt to existing and emerging markets for biomass products, and in turn identifying established and emerging technologies and processes that might link a given resource to a desirable product. An important aspect of examining these processes has been identifying synergies that may exist, and pointing to opportunities to integrate processes for improved resource efficiency.

Testing and analysis of outcomes

This study has taken the form of a series of surveys. Conclusions have been drawn about what is best practice and what should be the way forwards for the development of

biorefineries in the Wheatbelt. The fundamental test of the viability of a project concept is based on what people are willing and able to do. In this spirit, discussions with potential stakeholders have been an important testing ground for ideas and interpretations during the development of this study. A sense that recommendations and observations are in line with global trends provides important perspective.

Discussions with stakeholders in the region and at Murdoch University have been supportive of the conclusions drawn. Global trends are in line with the suggestions made for the development of biorefineries in the Wheatbelt, particularly in the sense of starting with wastes and moving to purpose grown feedstocks once the industry is established. The major point of difference is that this study has identified externalities (environmental and social benefits of biorefining) as macro drivers for the concept, whereas the international tendency is to approach biorefining from a traditional business case point of view.

Further work

The Roadmap chapter of this study (chapter 10), points to a way of proceeding with the biorefinery concept. In terms of further works that are needed to extend and expand the utility of this study, a number of avenues should be explored corresponding with each section of the study.

- In terms of biomass policy (chapter 1), analysis of the sensitivity of biorefinery project business cases to the inclusion of mechanisms to compensate for external effects, such as price on carbon emissions, and perhaps a salinity solutions incentive (funded by a levy) for the Wheatbelt would assist policy makers in setting a conducive environment
- Also in chapter 1, more specific avenues for funding should be explored so that a potential project developer can get an early sense of how much help will be available
- In terms of Markets (chapter 3) some research on co-firing of biomass in coal fired thermal electricity plants could reap benefits in CO₂ emissions from power stations and provide a ready local market for biomass pellets
- Also related to potential markets, butanol was identified as an overlooked biofuel option that is picking up considerable momentum in other countries, particularly with the partnership of BP and DuPont to investigate producing the fuel. Murdoch University should be up to speed with this fuel and ready to help local industry skip over ethanol directly to butanol
- In Technologies (chapter 4) there will be a need to develop the means to extract the various components of a feedstock. This is achieved by hydrolysis and direct extraction, but the specifics should be developed based on the chosen feedstock
- The Resource section (chapter 5) identified chaff as a potential biorefinery feedstock but the specifics of efficient collection and transport of this material need more resolution
- Other resources that should be further explored include sewage (generally treated in pond systems in each town), and poultry and piggery manure

- The idea of industry hubs (chapter 6) is driven by the availability of good frameworks for sharing (such as established contractual systems for sharing resources) and on communication and human interaction. It is recommended that the Wheatbelt Development Commission form a taskforce to facilitate the development of the biomass industry and associated hubs
- Murdoch University involvement in a biorefinery concept in the Wheatbelt (chapter 9) could be very beneficial for both the university and the region, and should be driven from within the university by the formation of an interfaculty group that could keep the concept alive and bring research applications into focus
- Finally, this kind of survey could be done more efficiently with the help of a software tool. Advanced systems engineering tools, developed to help machines to make better decisions, could find application in assisting human decision making also. Some of the approaches in this study could be the basis of an expert system to guide the development of projects that are multi-faceted and that may include integrated processes

In Conclusion

The problems facing the Wheatbelt are grave, and require action, but they present opportunities for the development of innovative projects. If means can be found to make some of the external benefits of the concept examined in this study, internal to the economics of projects based on the concept, a new way of doing things in the Wheatbelt is possible. Even without these extra inputs, some projects are likely to be viable and should be encouraged.

Many people have contributed to a large body of work that can be drawn on to develop projects. There are also many people in the region and the state committed to the idea that a new way of doing things in the Wheatbelt is possible, and so there is a momentum to this concept that should be maintained.

Murdoch University has the potential to be involved in this area through strong expertise in sustainable energy and in process engineering, as well as through a number of other research streams such as desalination and agricultural science.

There is a positive future for biorefining in the Wheatbelt of Western Australia.

APPENDIX 1: RESOURCE DETAILS

Biomass Source (2008-09)	Area ('000 ha)	Production (kt)	Yield (t/ha)	Available Fraction (%)	Available (kt)	Base Price (\$/t)	Compensation for Nutrient Losses (\$/t)	Delivered Price (\$/t)	Energy Content (GJ/t)	Energy content of Nutrient Replacement (GJ)	Total Balance of Available Energy Content (GJ)	Total energy electricity equivalent (GWh)	Electricity Unit Price (\$/MWh)	Ethanol Conversion Yield (kL/t)	Ethanol Production (kL)	Biodiesel Conversion Efficiency (%)	Biodiesel Production (kL)
Wheat (Kernels)	4900	8915	1.81938	0.00%	0	286		286	16.3		0.0	0.0		0.32			
Wheat Chaff		1960	0.4	100.00%	1960	40	4.8	44.8	12.8	0.2	24598000.0	1366.7	64.2	0.17	333200.0		
Wheat Straw		4410	0.9	0.00%	0	40	4.8	44.8	12.8	0.2	0.0	0.0		0.07			
Wheat Process residue		4457.5		100.00%	4458	15		15	12.8		57056000.0	3170.0	21.1				
					0						0.0						
Oats (Groats)	280	563	2.010714	0.00%	0	233		233	17.3		0.0	0.0		0.32			
Oat Chaff		112	0.4	100.00%	112	40	4.8	44.8	12.8	0.2	1405600.0	78.1	64.2	0.17	19040.0		
Oat Straw		252	0.9	0.00%	0	40	4.8	44.8	12.8	0.2	0.0	0.0		0.07			
Oat hull		281.5		100.00%	282	15		15	16.3		4588450.0	254.9	16.6				

Biorefining in the Wheatbelt

Biomass Source (2008-09)	Area ('000 ha)	Production (kt)	Yield (t/ha)	Available Fraction (%)	Available (kt)	Base Price (\$/t)	Compensation for Nutrient Losses (\$/t)	Delivered Price (\$/t)	Energy Content (GJ/t)	Energy content of Nutrient Replacement (GJ)	Total Balance of Available Energy Content (GJ)	Total energy electricity equivalent (GWh)	Electricity Unit Price (\$/MWh)	Ethanol Conversion Yield (kL/t)	Ethanol Production (kL)	Biodiesel Conversion Efficiency (%)	Biodiesel Production (kL)
Barley (Barleycorns)	1250	2527	2.0216	0.00%	0	259		275.7	16.7		0.0	0.0		0.32			
Barley Chaff		500	0.4	100.00%	500	40	4.8	44.8	12.8	0.2	6275000.0	348.6	64.2	0.17	85000.0		
Barley Straw		1125	0.9	0.00%	0	40	4.8	44.8	12.8	0.2	0.0	0.0		0.07			
Barley Process Residue		1263.5		100.00%	1264	15		15	12.8		16134895.0	896.5	21.1				
Canola (Seeds)	620	1138	1.835484	0.00%	0	580		580	28.5		0.0	0.0					
Canola Chaff		248	0.4	100.00%	248	40	4.8	44.8	12.8	0.2	3112400.0	172.9	64.2	0.17	42160.0		
Canola Straw		558	0.9	0.00%	0	40	4.8	44.8	12.8	0.2	0.0	0.0		0.07			
Canola Oil		250.48	0.404	0.00%	0			0	39.0		0.0	0.0				97.0%	276980.8
Canola Meal		533.2	0.86	0.00%	0	450		450			0.0						

Biorefining in the Wheatbelt

Biomass Source (2008-09)	Area ('000 ha)	Production (kt)	Yield (t/ha)	Available Fraction (%)	Available (kt)	Base Price (\$/t)	Compensation for Nutrient Losses (\$/t)	Delivered Price (\$/t)	Energy Content (GJ/t)	Energy content of Nutrient Replacement (GJ)	Total Balance of Available Energy Content (GJ)	Total energy electricity equivalent (GWh)	Electricity Unit Price (\$/MWh)	Ethanol Conversion Yield (kL/t)	Ethanol Production (kL)	Biodiesel Conversion Efficiency (%)	Biodiesel Production (kL)
Lupins	267	341	1.277154	0.00%	0	261		261	18.4		0.0	0.0					
Lupin Chaff		106.8	0.4	100.00%	107	40	4.8	44.8	12.8	0.2	1340340.0	74.5	64.2	0.17	18156.0		
Lupin Stalks		240.3	0.9	0.00%	0	40	4.8	44.8	12.8	0.2	0.0	0.0		0.07			
Lupin Process Residue		170.5		100.00%	171	15		15	12.8		2182400.0	121.3	21.1				
Oil Mallee	14	175	12.5	100.00%	175	45		45	19.3		3377500.0	187.7	42.0				
Forestry waste		539		100.00%	539	30		30	17.4		9351650.0	519.6	31.1				
Green Waste		3		100.00%	3	0		0	9.0		27000.0	1.5	0.0				
Tallow / Used cooking oil		25		100.00%	25	750		750	39.0		975000.0	54.2	346.1			97.0%	27645.0

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